SHORT COURSE IN MECHANICAL DRAWING

WM. A. DE VETTE

Brent Malin

A Short Course in Mechanical Drawing

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Wm. A. De Vette

Instructor in Drafting, Wilson High School and Pennsylvania State College Engineering Extension, Erie, Pa.

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PREFACE

This volume has been developed with the idea of giving a rather comprehensive course in mechanical drawing to those students who find it impossible to devote the usual amount of time to the subject. The material has been used successfully in evening-school classes, recently also in day high-school classes, and to a limited degree in junior-high-school classes. During the past three years it has been used further, with a few omissions, in college-engineering-extension classes where it seems excellently suited.

The final form of the book has been influenced by the fact that most teachers must allow considerable individual work on the part of their students. The figures have been made especially large for legibility under widely different light conditions.

The author wishes at this time to give his heartfelt thanks to his associates, John F. Faber and Dorcey E. Kellogg of the Erie, Pa., schools for their help and inspiration.

WM. A. DE VETTE.

Erie, Pa.
December, 1928.

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A Short Course In Mechanical Drawing

CHAPTER I

INTRODUCTION

Mechanical Drawing. Mechanical drawing is taking its place as one of the most important of all modern languages—the language of industry. It is a universal language, understood and used by technical men the world over. It is the graphic expression of the thoughts of the engineer, the designer, the mechanic, in fact, every expert craftsman.

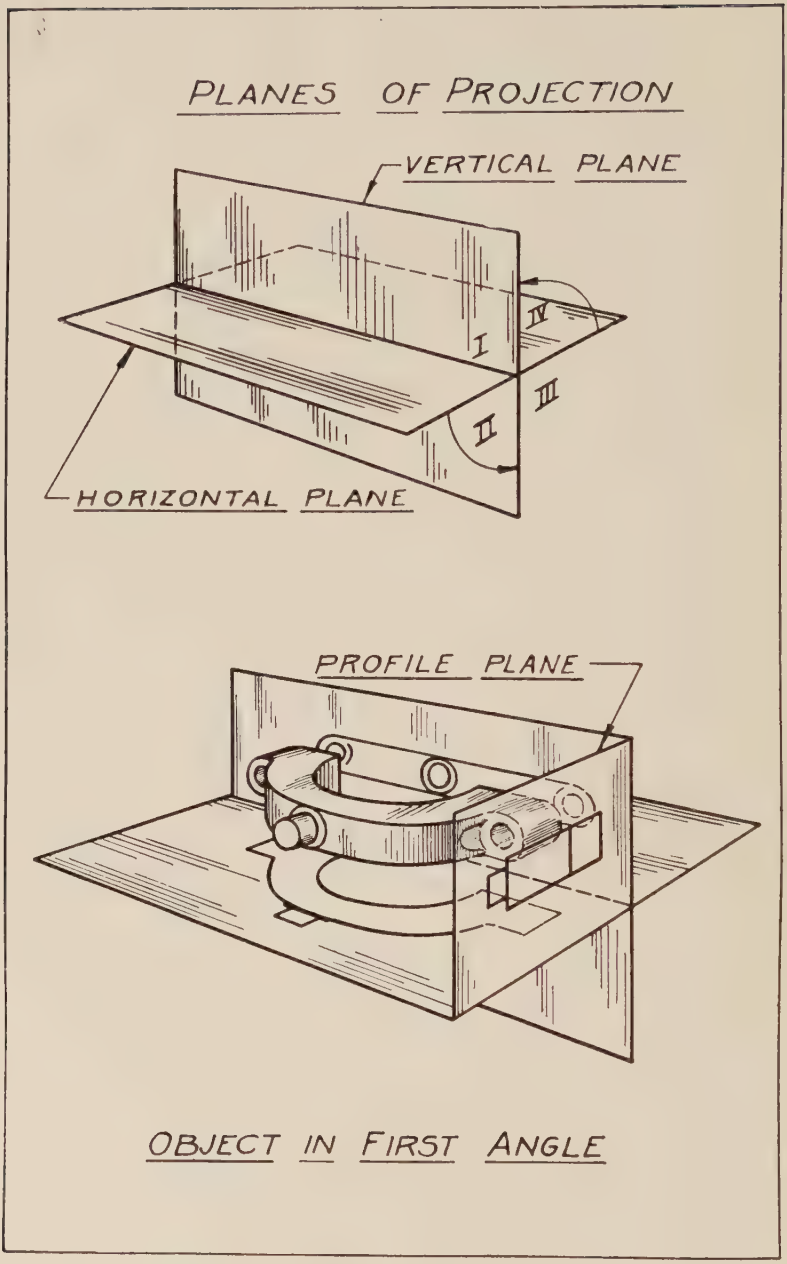
Practically no comparison can be made between mechanical and free-hand drawing. A free-hand drawing, as commonly thought of, is an expression of beauty presented in line, color, light, and shade. A mechanical drawing is a work of accuracy and careful calculation, embodying instructions for the construction of some manufactured or assembled object.

A draftsman is not limited to one point of view, as the artist is, but he may show on one drawing all sides of an object, and, if he desires, even the interior. To explain the method by which this may be done is to strike at once at the very foundation of mechanical drawing, that is, orthographic, or true-view projection.

Orthographic Projection. Orthographic projection is the drawing of two or more views of an object and the placing of these views in proper relation to each other.

There are in practical use two methods of orthographic projection, first-angle and third-angle, respectively. First-angle projection is used in Europe, while third-angle projection is the generally accepted method in America. The difference lies only in the placing of the views; but if a drawing is not made according to the generally accepted method, and does not state this fact, it is likely to be very misleading.

A short explanation of first-angle projection will be given, and third-angle projection will be taken up more in detail as it is of much greater importance to us.


PLANES OF PROJECTION
VERTICAL PLANE
I
II
III
IV
HORIZONTAL PLANE
PROFILE PLANE
OBJECT IN FIRST ANGLE

Figs. 1 and 2

First-Angle Projection. In both methods, two intersecting planes are used primarily and a third is added later in further development. The two planes of primary importance are called the horizontal and the vertical planes, while the other is referred to as the profile plane. These planes are supposed to be imaginary, but an attempt is made to help the student visualize them in Figures 1 and 2.

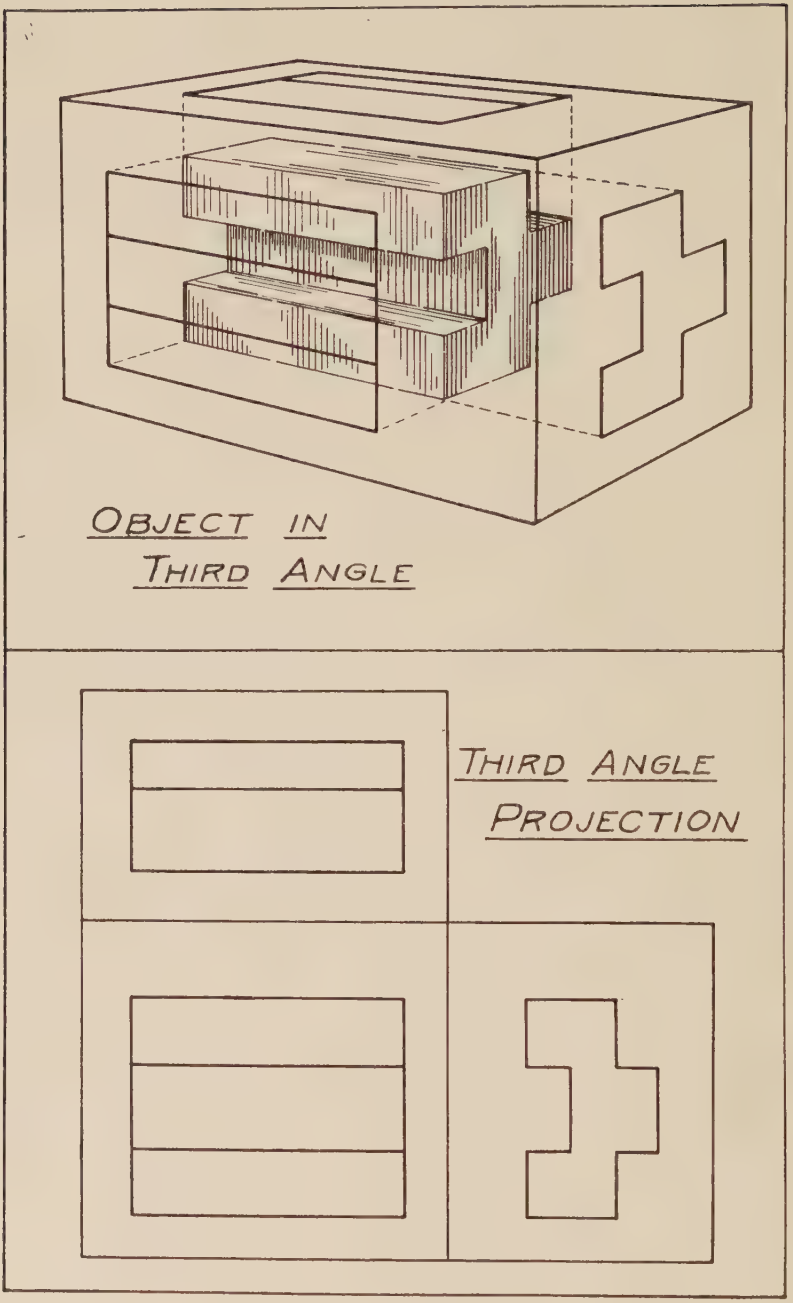
These two planes fold into each other by the rotation of the horizontal plane about the intersection of the two, as shown by the arrows. The angles are numbered counterclockwise, as is also shown in Figure 1. Thus, an object placed in front of the vertical plane and above the horizontal is in the first angle. This is illustrated in Figure 2.

Suppose that a person is standing at a distance from the object so placed. His lines of vision, projected beyond the object to the vertical plane, will place thereon a view of the object as it appears from the front.

If the rays of vision are assumed to be coming from above, then they will project, on the horizontal plane, a top or plan view of the object. Similarly, if the rays of vision are assumed to be coming from the left, a left-end view will be projected on the profile plane.

These planes are now to be revolved about their intersections with the vertical plane, until they are in the same plane with the vertical. This would bring the top view below the front view, and the left-end view at the right of the front view. This does not appear logical, as it would seem that the top view should be above the front view, and the right-end view at the right of the front view. This is accomplished by placing the object below the horizontal and behind the vertical plane, thus putting it in third-angle projection.

Third-Angle Projection. When the object is placed in the third angle, and viewed as before, the rays of vision are projected through the plane to the eye. The views on the planes will still be the same as before, but so placed (Fig. 3) that when the horizontal and profile planes are revolved into the vertical, the top view will be directly above the front view, and the right-end view will be at the right of the front view.



Figs. 3 and 4

Figure 4 illustrates the planes revolved into the vertical. It shows the three views as they would appear in relation to one another in an orthographic drawing, or what is usually termed a "mechanical drawing," regardless of whether instruments were, or were not, used in making it.

Instruments. At the beginning of any undertaking, equipment and materials receive first consideration. This is also true of mechanical drawing. The selection of instruments for mechanical drawing is of great importance, because good work cannot be done with poor instruments. As the cost of good instruments for mechanical drawing is rather high, it is well for a student to seek expert advice in their selection.

In some schools, sets are issued to the students, and in some factories sets are loaned to apprentices and presented to them at the completion of the course. The instruments and supplies needed for the proper development of this course are the following:

Drawing board: for drawings up to 22 by 30 in.
T square: 30-in.
Triangle: 45°, 8-in.
Triangle: 30° x 60°, 10-in.
Architect's scale: 12-in.
Set of instruments, including
  5½-in. compass with pencil leg, pen leg, and lengthening bar
  5-in. hairspring or plain dividers
  5½-in. ruling pen
  Bow pencil
  Bow pen
  Bow dividers
Pencils, 3H and 4H preferred
Thumb tacks
Combination file and tack lifter
India ink
Pen points, Gillott's 303 or 404, or equal
One or more irregular curves
Pencil eraser
Drawing paper
Tracing paper or tracing cloth

Sizes of Drawings. Whenever a large number of drawings is to be made, it is necessary, for purposes of filing and easy access, to arrange for standard sizes of sheets.

Several systems are in use in the United States, but there are two which, from a standpoint of economy and uniformity in filing, seem to be the best. The first of these begins with a

sheet 24 by 36 in. and its subdivisions as follows: 18 by 24 in., 12 by 18 in., 9 by 12 in., and 6 by 9 in.

The other has for its basis the standard letter size used in commercial practice, which is $8\frac{1}{2}$ by 11 in. The fractional sizes are not exact multiples of this sheet, but allowances are made

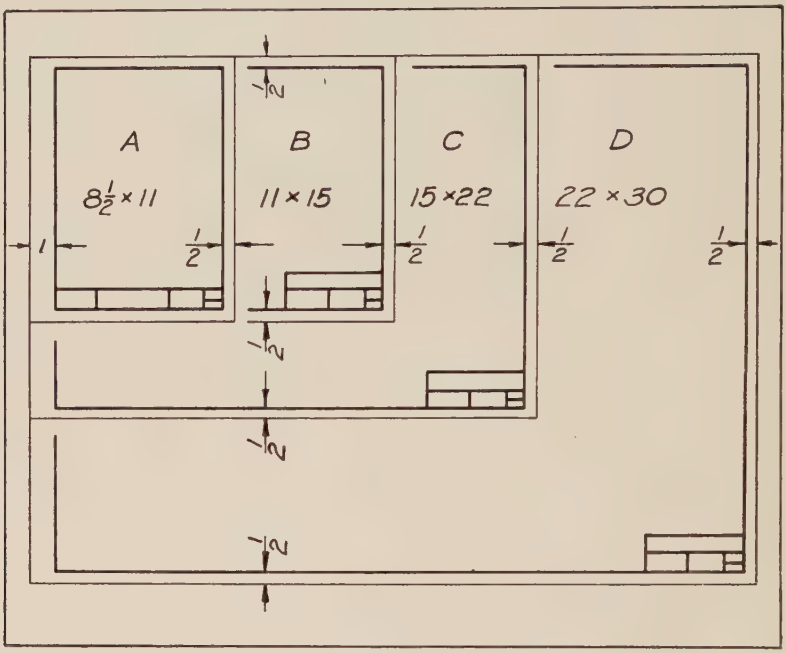


Fig. 5

for binding and for folding. All of these, with the exception of the smallest, can be cut without waste from a sheet which is 22 by 30 in. in size. The sizes for the drawings in this system are as follows: $8\frac{1}{2}$ by 11 in., 11 by 15 in., 15 by 22 in., and 22 by 30 in. Figure 5 gives a diagram of the sheet sizes, the location of the margin lines, and a suggestion for the title plates.

Title Plates. Title plates are placed on the drawings, to give the following information:

Name of the manufacturing concern.

Location of the manufacturing concern.

Name of the article shown in the drawing.
Material from which it is to be made.
Heat treatment to which it must be subjected.
Number required on a machine.
Names of draftsman, tracer, and checker.
Date of completion of the tracing.
Scale of the drawing.
Number of the drawing.
Number of corresponding assembly drawing.
Pattern number.

Fig. 6

All of these items, of course, are not required on every type of drawing or title plate. The nature of the manufacturing concern and the kind of product will determine what information the title plate must convey. Examples of title plates serviceable for school use are shown in Figures 6 and 7.

Lettering. Lettering is used on drawings for notes and other information which cannot be conveyed by the lines of the drawing. The system in most common use is the one in which all of the letters are made with a slant of about 15 degrees with the vertical.

The ability to do neat lettering comes only after long practice. The evening-school student is therefore advised to have the strokes explained to him by the instructor in class, and to do his practicing at home during spare time. The practice work should be brought to class for the instructor's criticism.

A pad of lettering exercises will serve best as a guide. Several of these are now on the market, and it is a matter of personal opinion as to which is the best.

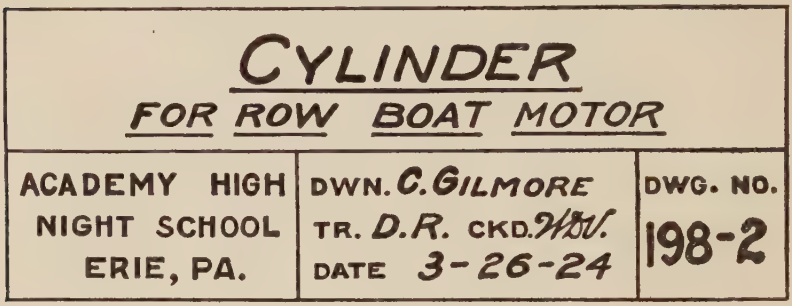


Fig. 7

Manufacturing concerns differ in the type of lettering required on their drawings. This should be taken into consideration, if the student is preparing to enter the employ of a company which has its own system of lettering.

Figure 8 shows the numerals and the capital letters and small letters of the Roman alphabet. The term "upper case" is usually applied to capital letters, and "lower case" is applied to small letters. These names are borrowed from the printers who place the type for capitals in an upper case and the smaller letters in a lower case.

Most draftsmen are required to use only upper-case letters, and for this reason the standard strokes in making upper-case letters are illustrated in detail in Figure 9. In this figure, the letters and numerals are shown in the progressive order of the strokes by which they are made. That is, in making numeral 8, four strokes are used: the first is the left side of the upper section; next, the right side of the upper section; third, the left side of the lower section; and last, the right side of the

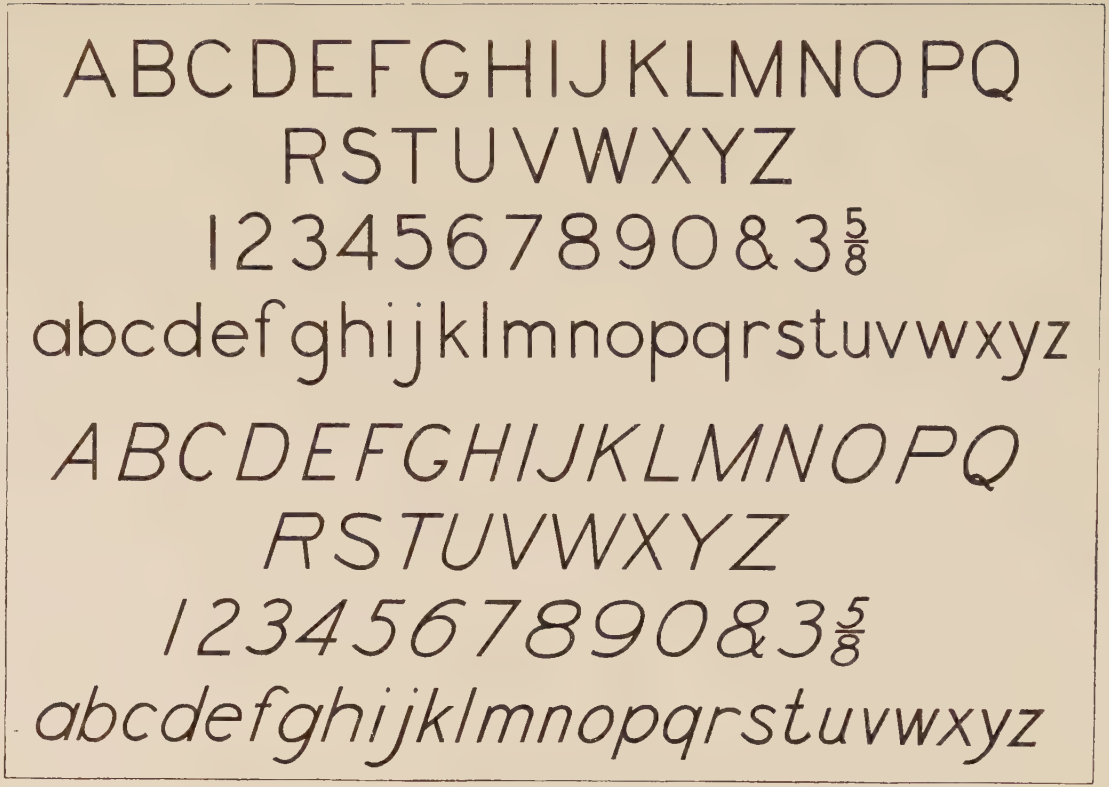

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Fig. 8

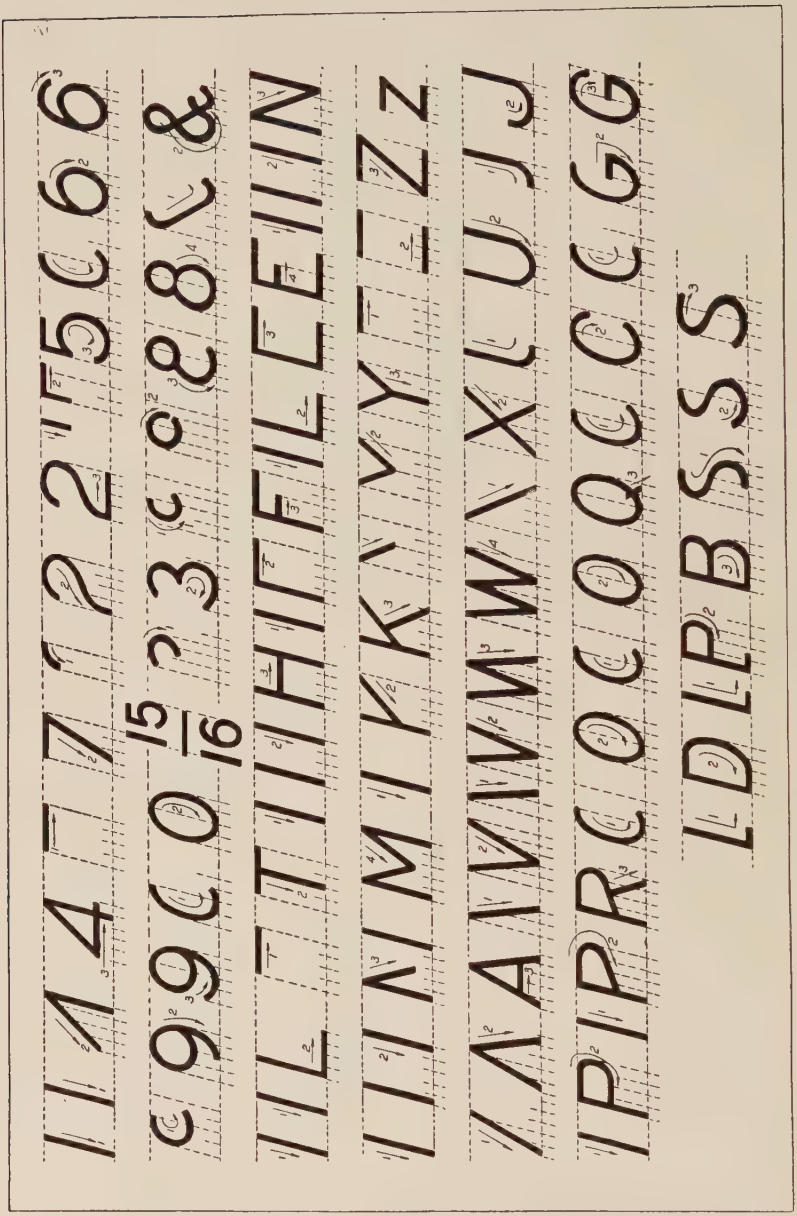


Fig. 9

lower section. In each succeeding figure, the next stroke is added to illustrate the progress of the letter in construction.

In learning to letter, it is well to learn the proper construction of the letters by grouping them according to the strokes used in making them. That is, the letters I, H, L, F, E, and T should be taken together, because in these only vertical and horizontal strokes are used. Next, the letters involving diagonal strokes should be practiced, and after that, the letters involving curved strokes.

Due to the fact that the student will be required to dimension drawings almost immediately after the beginning of the course, it is best to practice the numerals first, so that the drawings will not be marred by poor figures in the dimensioning. A good drawing may easily be ruined by poor lettering, while good lettering will aid the appearance of an otherwise mediocre drawing.

A similar course should be pursued in practicing the numerals as in practicing the letters. That is, the 1, 4, and 7 should be practiced first; next the 0, 6, and 9; third, the 3 and 8; and last, the 2 and 5.

When the student has mastered the strokes, and can make letters of fairly uniform shape and slant, he should begin to practice on groups of words in complete sentences, as this will be the best aid to correct spacing. The letters in each word should be placed close together, while a space at least as wide as a full letter should be left between words. Good spacing is a great help in reading the lettering and adds to its appearance.

Care must be taken to use only downward and horizontal strokes in making the letters, as it is very difficult later to use any other strokes than these on tracing cloth.

CHAPTER II

DETAIL DRAWINGS

Working Drawings. In the manufacture of an article, all the planning is done by a planning department or an engineering department. Sometimes these departments are separate units, the engineering department making all the drawings and preparing the specifications, and a production department planning the process of manufacture. This course is interested in that part which concerns the making of the drawings.

A drawing is made of the article or machine to be manufactured, and on this drawing all of the parts are shown in the proper working position in relation to each other. This is called an "assembly" drawing, and serves two purposes in the manufacture of the machine.

The first purpose of the assembly drawing is to discover if the principle of the machine is sound, and if it is so designed that it will do the work for which it is intended. Upon this drawing all the scheming and figuring is done, and if the machine under consideration is of any importance, it is possible that several conferences will be held in which this drawing is the main bone of contention. The various functions of the machine are discussed, and points in its design may be questioned by one or more of the designers present.

The second purpose of the assembly drawing comes to the front after the general design of the machine has been approved. This drawing furnishes the dimensions and the information for the separate drawings which must be made for each piece of the entire machine. Each of these drawings must convey all the information necessary for the construction of the particular piece. The drawing must indicate the exact shape, and there must also be sufficient information regarding the size of the piece, the method of manufacture, and the degree of accuracy which must be attained, in order that the

piece may function properly when assembled with the rest of the machine. This type of drawing is called a "detail" drawing. Both assembly and detail drawings are called "working drawings."

While in the design of a machine, the assembly drawing is made first, in learning to draw, the opposite is true; detail drawings must be studied first, and the assembly drawings are to be taken up later.

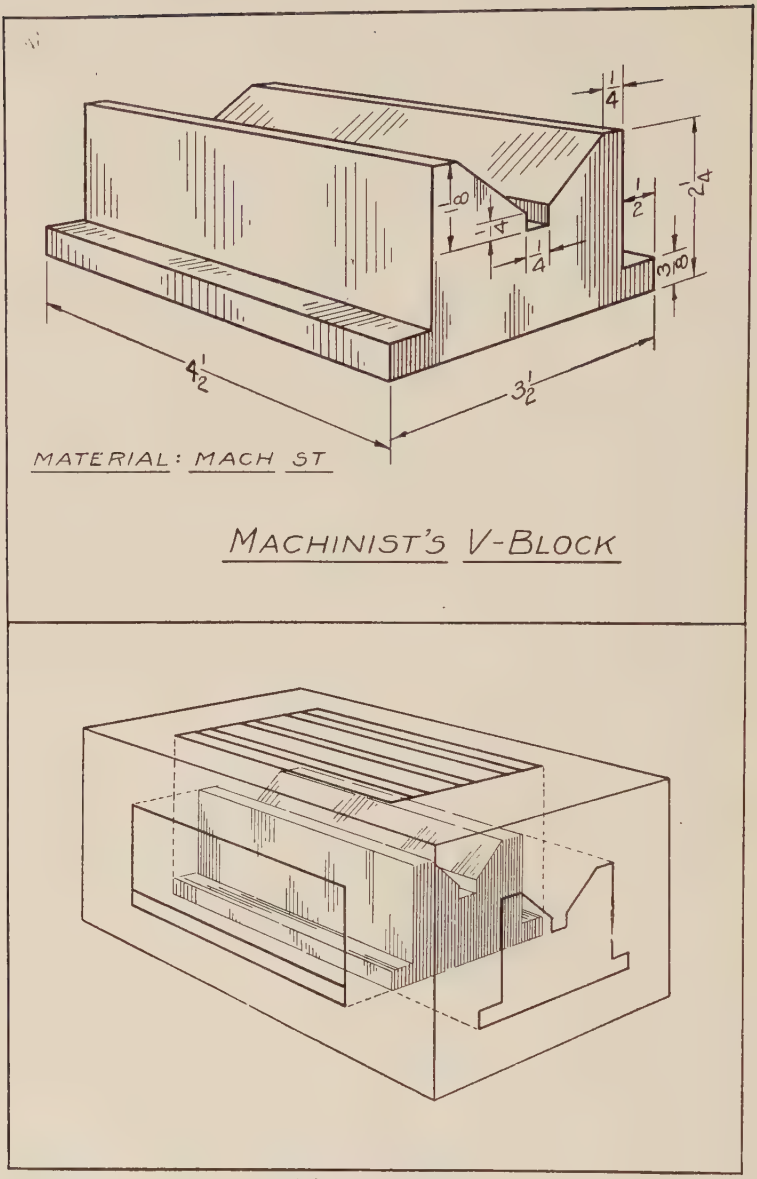
This drawing course will begin with a simple object commonly used in the machine shop, although it cannot be considered a machine part. A study of this piece will be made with the intention of making a detail drawing of it.

Detail Drawing of a V Block. The first drawing to be made in this course is a machinist's V block. A perspective of this block is shown in Figure 10. In considering this block, it should be thought of as placed under a set of planes of projection such as were discussed in the previous chapter. Figure 11 illustrates the block so placed in the third angle. From the block in this position, it is possible to project a top view on the horizontal plane, a front view on the vertical plane, and a side or end view on the profile plane. These views are shown in their proper relation as they would appear on the planes of projection.

By folding the horizontal plane and the profile plane into the vertical, a single surface is obtained on which all of the views mentioned are shown in the proper relation to each other. The draftsman's paper takes the place of the projection planes which have been folded into a single surface.

Preparation for Drawing. The drawing of the V block should be made on a sheet 11 by 15 in. on which the margin lines are to be placed as shown in Figure 5, and the title plate as in Figure 7. The paper must be tacked on the board within easy reach of the draftsman, usually near the upper left-hand corner. (These instructions will be reversed for a left-handed draftsman.)

The T square is placed on the paper with the head against the left-hand edge of the board, and the paper is "lined up" with its upper edge parallel to the upper edge of the T square.



Figs. 10 and 11

Two opposite corners of the paper are fastened with tacks. It is then smoothed out, and the other corners are fastened down in the same way.

Next, the margin lines are measured off and drawn. The horizontal lines are drawn along the upper edge of the T square, working from left to right. The vertical lines are drawn from the lower end upwards along the edge of one of the triangles, which is laid with one edge against the T square, the slanting side toward the right and the vertical side toward the left. It is practically impossible to work with ink later on, unless this method is strictly adhered to.

Selection of Views. The selection of the views for this drawing is made for the student in Figure 11, where the block is shown under the planes of projection. The views to be drawn are the top, front, and right end.

Blocking in the Views. The V block is $4\frac{1}{2}$ in. long, $3\frac{1}{2}$ in. wide, and $2\frac{1}{4}$ in. high. The sizes of the views, therefore, will be as follows:

Top view, $4\frac{1}{2}$ by $3\frac{1}{2}$ in.
Front view, $4\frac{1}{2}$ by $2\frac{1}{4}$ in.
End view, $3\frac{1}{2}$ by $2\frac{1}{4}$ in.

A space should be allowed between views. In this drawing, the allowance may be as much as $1\frac{1}{2}$ in. A good method to use in locating the views on the paper is to add the width of the top view, the distance between the views, and the height of the front view together. Then subtract the total from the distance between the upper margin lines and the top of the title plate, in order to obtain the space left at the top and bottom. The remainder, divided by two, will then give the distance which is to be allowed between the upper edge of the top view and the upper margin line. In the case of the drawing for the V block, the distance is $\frac{5}{8}$ in. In the same way, the length of the front view and the width of the end view can be added together with the distance between views. The total can then be subtracted from the distance between the left- and right-hand margins, and the result divided by two, to give the distance of the left-hand edge of the front view from the left-hand margin line. When these two distances have been determined, the lines de-

noting the upper and lower limits of the views can be drawn as well as the left- and right-hand edges of all the views.

This step should never be omitted, for much time would be lost if a draftsman made one view of a machine part and then found that he could not get the other view on the same paper. This first stage in the making of a mechanical drawing is called "blocking-in the views."

Completing the Views. After locating the views, the next step is to complete the views by working from the perspective in Figure 10, which gives all the dimensions of the block. Wherever possible, the student should project from one view to the other with his T square, or T square and triangle, instead of measuring the same distance along the scale in each view.

The lines which denote the outline of the object should be made heavier than the original blocking-in lines, to emphasize the appearance of the object, and to give a very clear conception of the shape of the piece.

Dimensions. The mechanical drawing of an object has a twofold purpose: First, to convey the shape of the object to the workman who is to make it; and second, to make clear the size of the object, or what are ordinarily termed the "dimensions" of the object.

Many times the mere sizes of the object are not sufficient. The method by which these dimensions are to be arrived at must be indicated; that is, the drawing must show in some way that the surface may be left rough, or that it is to be machined, or, as in cases of extreme accuracy, that it is to be ground. Indication, also, must be made as to whether the holes called for are to be cored out, drilled, reamed, or bored. The drawing must state from what material the object is to be made, and whether or not it is to be subjected to heat treatment.

From this, it appears that the draftsman must not only know how to draw, but must also be acquainted with the methods of the pattern shop, the foundry, and the machine shop. No draftsman can be expected to do his work intelligently if he does not have this knowledge.

Types of Dimensions. Under the subject of dimensions may be included all the information which must be given on the drawing and cannot be given by the lines of the drawing itself. Dimensions may be roughly classified into four types:

1. Distance between parallel lines.
2. Amounts of opening between intersecting lines.
3. Diameters or radii of circles.
4. Notes.

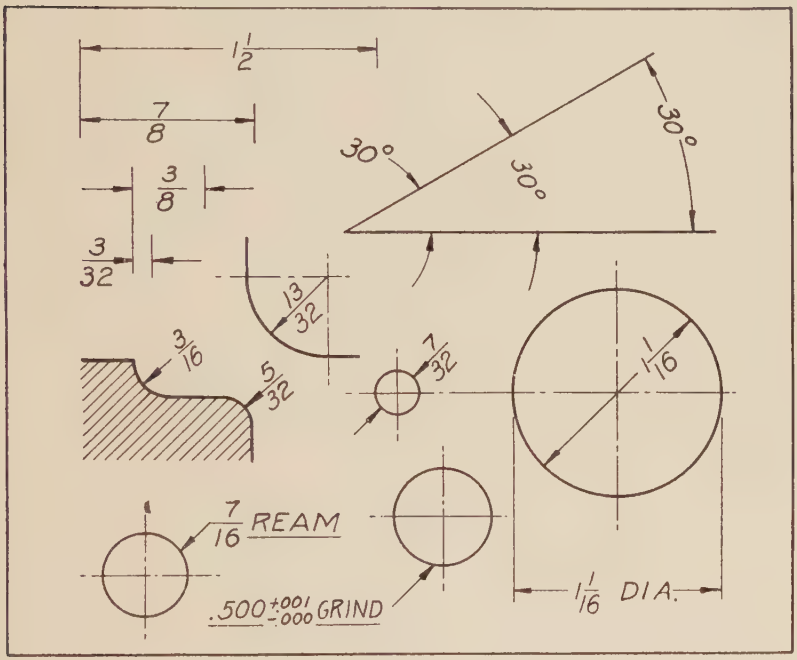
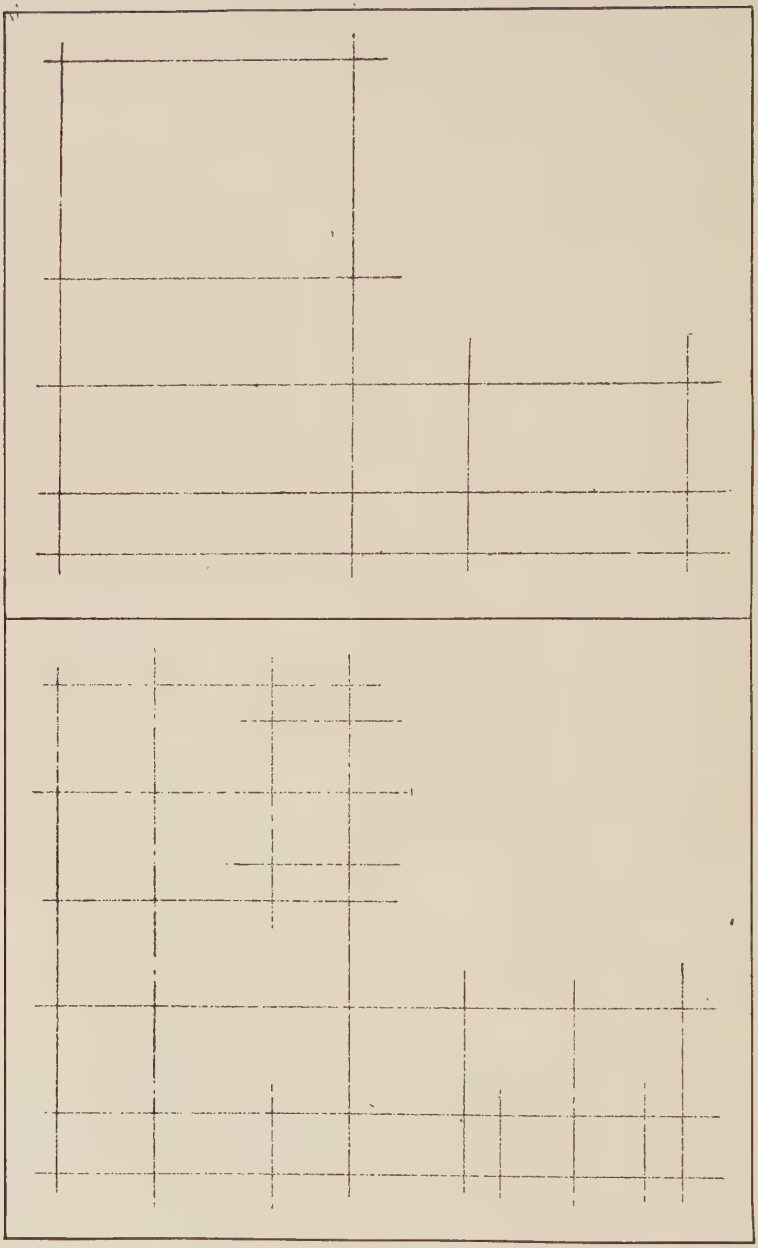


Fig. 12

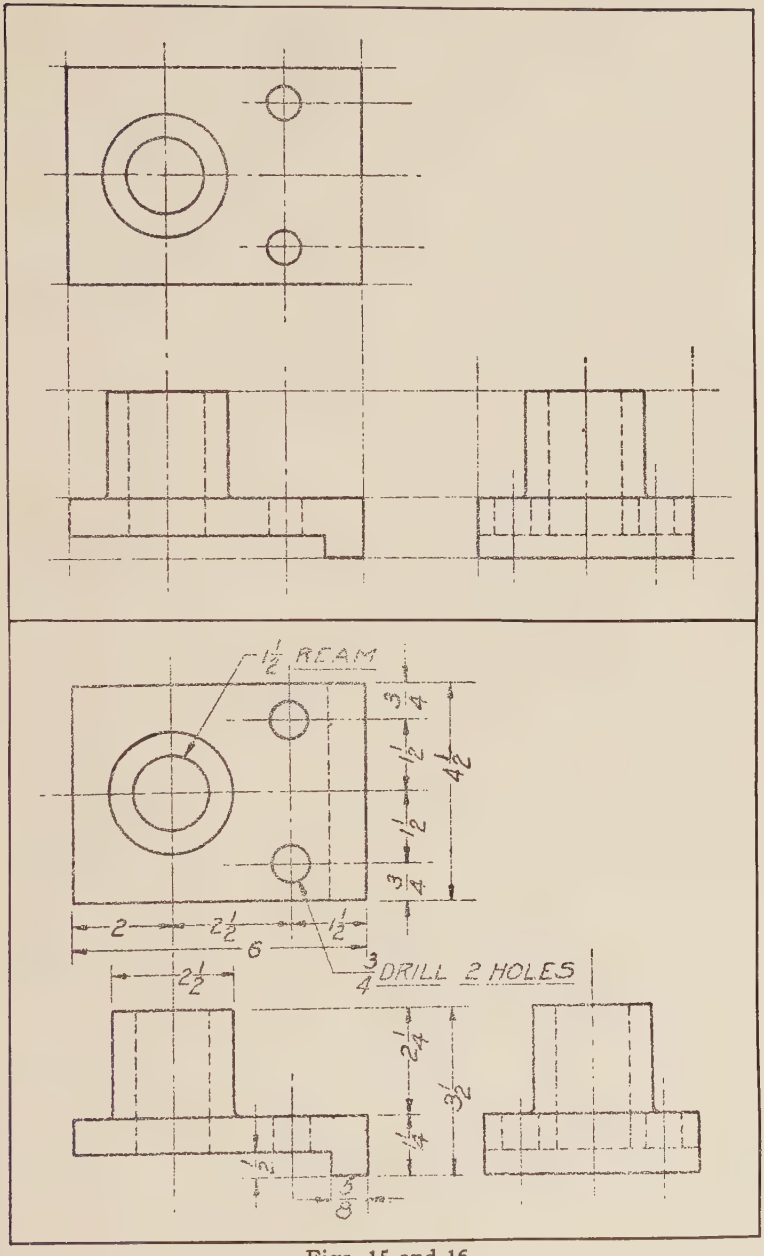
In Figure 12 all of these types of dimensions are illustrated. The first classification is shown in four different ways:

a) A distance greater than one inch, showing the dimension line broken so that the whole number may be inserted, while the second half of the line also serves as the fraction line.

b) A distance less than one inch, showing the dimension



Figs. 13 and 14



Figs. 15 and 16

line unbroken, with the numerator of the fraction above the line and the denominator below.

c) A limited distance between the lines, allowing room for the figure but not the arrowheads.

d) A still smaller distance, where there is insufficient room for either the arrowheads or the figure.

Similar cases for the dimensioning of angles are also given. The length of the sides as well as the size of the angle are factors which determine the method to be used.

Several methods for indicating radii and diameters of circles are given, both for large circles and for small ones, especially where room for arrowheads and figures is limited.

Notes are illustrated by the use of a leader pointing to a circle, indicating a hole, and giving the size and method by which it is obtained. Another circle indicates the method of showing the degree of accuracy to which the work must be carried.

Location of Dimensions. The best location for dimensions has always been the cause for argument among designers and draftsmen. A general rule to follow, but at the same time one to which there will be many exceptions, is to place the dimension between the views to which the dimension applies.

Whenever a distance is given by a series, or what is ordinarily called a "string" of dimensions, these dimensions should be totaled up and the total length given parallel to the shorter dimensions. This aids the draftsman to check his work, and is also a help to the mechanic in the shop. These dimensions are called "over-all" dimensions, and should be placed at the outside.

Stages in Penciling a Drawing. Figures 13 to 16 inclusive show the successive stages in the "penciling" of a mechanical drawing.

Figure 13 shows the "blocking-in" process. It definitely locates the limits of each view and assures enough space for the necessary dimensions.

Figure 14 indicates the position of the holes or cylindrical parts of the object by the use of center lines.

Figure 15 shows the drawing of the object completed. The lines of the object are made heavier to emphasize the shape.

Figure 16 is the completed drawing including the dimensions and notes necessary for the manufacture of the piece.

Cylindrical Parts. In dimensioning an object, part of which is cylindrical, it is often best to give both the diameter and the length of the part on one view, so the workman will not become confused and misinterpret the drawing. The size of a hole, however, is usually given on the view in which the shape of the hole is indicated, especially if the hole goes through the object so that the depth need not be shown.

Checking. When a drawing is thought to be complete, it is turned over to a checker, (usually a draftsman of wide experience in design and actual shop practice) for the purpose of finding any mistakes and missing dimensions and, if possible, any defects in the design itself. This checking should never be omitted in shop practice, and even if only two draftsmen are employed at a place, one should always check the other's work.

Dimensioning the Drawing. The dimension lines on a drawing should be made light, so that they will not be confused with the object lines. The extension lines—those running from the object to the dimension lines—should be the same weight as the dimension lines and should not touch the object. The arrowheads should be made very plainly and carefully, as any tendency toward fancy arrowheads detracts from the clearness of the drawing. Dimension lines must not crowd the object, but should be at least $\frac{1}{4}$ in. away from the nearest object line.

The drawing of the V block should be dimensioned according to the above principles. The figures should be so placed on the dimension lines that, when the drawing is read from the lower right-hand corner, none of the figures will be inverted.

Invisible Edges. When a machine part is so constructed that an edge must be shown in a view in which it is invisible, or hidden, a distinct type of line must be used, so that there will be no confusion between the visible and the invisible edges of the drawing. The type of line used for this purpose is one

made up of dashes, approximately $\frac{1}{8}$ in. long, spaced very closely together. These lines are commonly called "hidden" lines.

The Clamping Plate. The clamping plate illustrated in Figure 17 is a lathe part, in the drawing of which hidden lines must be used. The plate itself is of simple construction, and can be made sufficiently clear in two views.

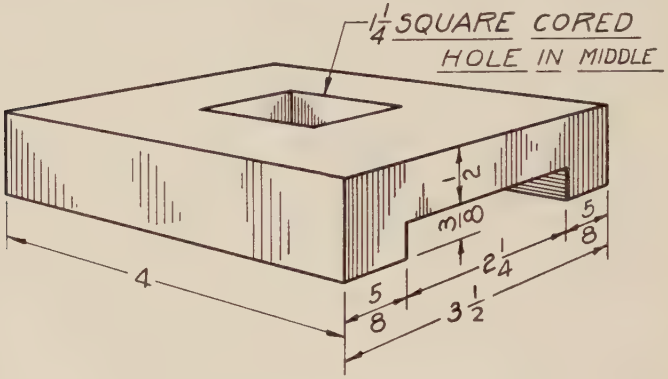


Fig. 17. Clamping Plate

The drawing of the clamping plate should be made on an A-size sheet, and the top and front views should be drawn. See Figure 5 for the size of sheet and the location of the margin lines. Leave approximately $1\frac{1}{2}$ in. between the views. The front view will show the square-cored hole in hidden lines, while the relief on the underside of the piece will be shown in hidden lines in the top view.

Cylindrical Objects. In mechanical drawings of cylindrical objects, usually only two views are necessary, as the object, when revolved upon its axis, always presents the same view, making a side view superfluous.

Center Lines. When drawing cylindrical objects, the views are not located as previously outlined, but from center lines instead. Center lines are drawn by alternating a short dash about $\frac{1}{16}$ in. long with a longer dash, which may be anywhere from $\frac{3}{4}$ to $1\frac{1}{4}$ in. long, or even longer. It is also called the "dot-and-dash" line.

Center lines are used to locate the center of a circle. In fact, no circle is considered complete unless both the horizontal and vertical center lines are shown.

The Double-Flanged Bushing. The double-flanged bushing, shown in Figure 18, is a machine part which is cylindrical, requiring both center and hidden lines in the making of the mechanical drawing. Top and front views should be drawn and located from a center line drawn vertically through the middle of an A-size sheet.

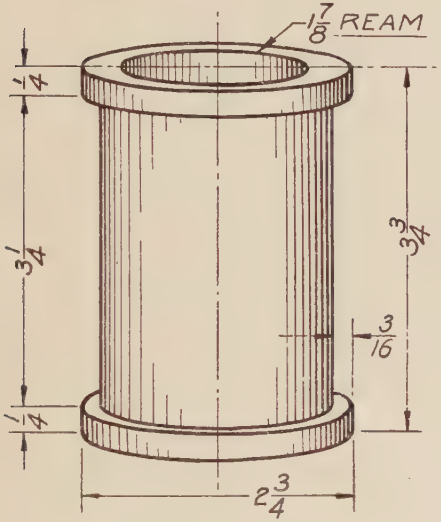


Fig. 18. Double-Flanged Bushing

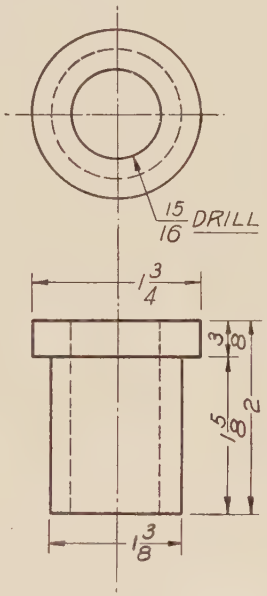


Fig. 19

An example of the use of center lines will be found in Figure 19, which is a drawing of a bushing having only one flange. Note that the center line is continuous through both views, and extends a short distance beyond on both ends. The figures $1\frac{3}{4}$ and $1\frac{3}{8}$ are placed at one side of the center line, and the dimensions are located as suggested for the dimensioning of cylindrical parts previously discussed.

The two views are located by adding the diameter of the front view, the distance between views, and the height of the

front view, and subtracting this total from the distance between the upper and lower border lines. The result is divided by two, to get the distance from the upper margin line to the top edge of the top view. However, as the circle is located from the center line and not from the edge, the radius of the top view must be added to this, in order to find the center line in the horizontal direction through the top view.

In making the drawing, begin with the top view. Then, when the front view is drawn, the width of each part may

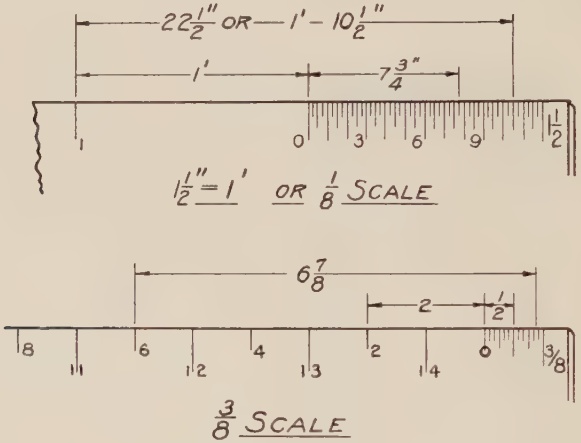


Fig. 20

be projected from the top view, rather than measuring these distances on the scale, as would have to be done if the front view were made first.

The hole through the bushing must be indicated by hidden lines in the front view, while the circle in the top view, which indicates the body diameter, must also be a hidden circle. When this has been completed, the entire piece can be dimensioned according to the general rules for dimensioning cylindrical objects.

Drawing to Scale. Many machine parts are so large that it is impossible to draw them full size on a sheet of paper which can be readily handled in the shop. Such pieces are drawn half size, one-fourth size, and sometimes even smaller.

The architect's scale used by mechanical draftsmen provides for this. Drawings may be made to smaller than actual scale by this method, without the necessity of dividing each dimension by the scale used, in order to obtain the length of the various lines. The scale of a drawing is usually given in inches per foot as follows: $6'' = 1'$, or 6 in. $= 1$ ft., for half-size drawings, and others correspondingly. The following scales per foot may be found on an architect's scale: $3''$, $1\frac{1}{2}''$, $\frac{3}{4}''$, $\frac{3}{8}''$, $\frac{3}{16}''$, $\frac{3}{32}''$, $1''$, $\frac{1}{2}''$, $\frac{1}{4}''$, $\frac{1}{8}''$.

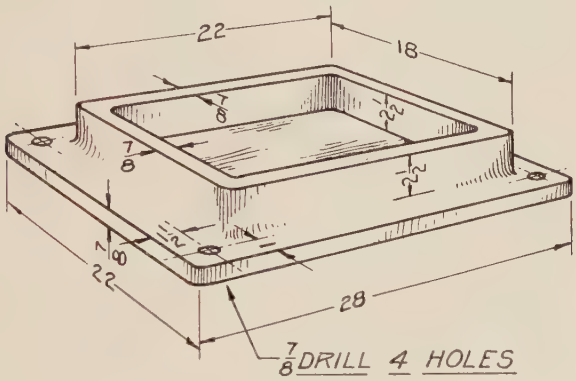


Fig. 21. Base Plate

In drawing to scale, it is suggested that the dimensions be set with the dividers. For example, in Figure 20, upper part, it is desired to obtain $22\frac{1}{2}''$ on the $\frac{1}{8}$ or $1\frac{1}{2}''$ per-foot scale. As this dimension is $1'\text{-}10\frac{1}{2}''$, the one point of the dividers is set on the $1'$ graduation, while the other point is set on the $10\frac{1}{2}''$ graduation on the other side of the zero mark. With the divider points thus set, it is a simple matter to transfer the distance to the drawing.

The Base Plate. The plate illustrated in Figure 21 should be drawn to a scale of $3'' = 1'$. Two views of the piece should be made on a B-size sheet.

The scale is often put to a use for which it was not originally intended. Drawings are made, for instance, to a scale of $\frac{3}{8}'' = 1''$ on the graduations intended to be used in making drawings to a scale of $\frac{3}{8}'' = 1'$. There are many occasions

when a drawing would be too large half size, and too small for convenient use if made one-fourth size. The one disadvantage

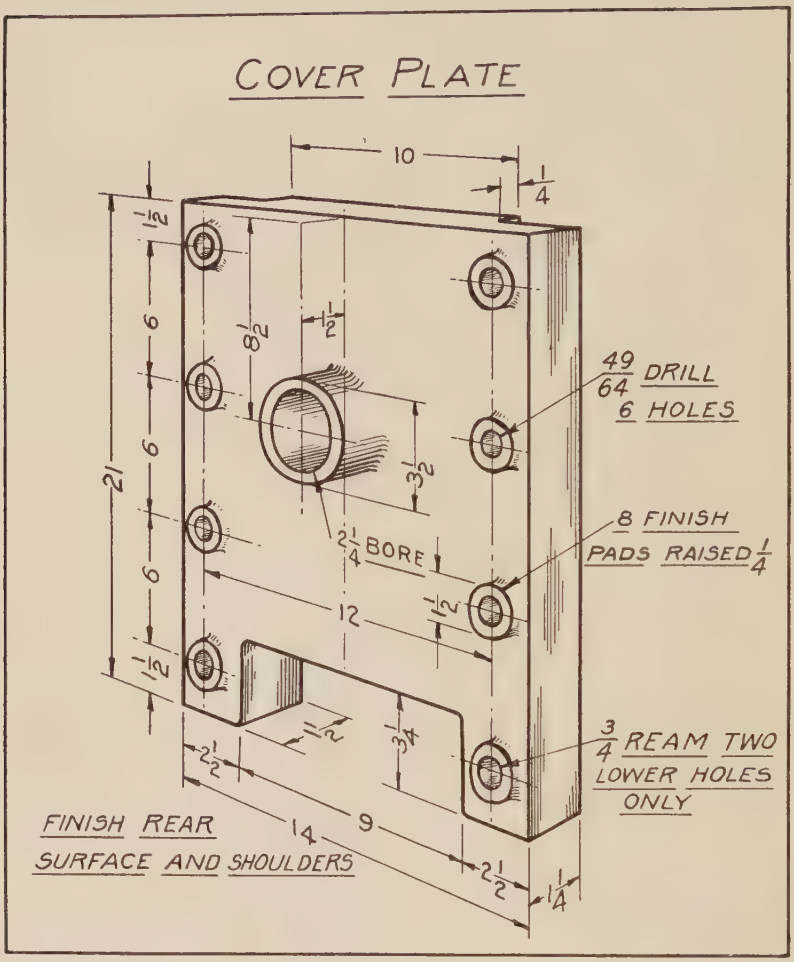


Fig. 22

in drawing to this scale is that the unit at the end is divided into twelve parts, or inches per foot, instead of sixteen parts per inch. Thus, any fractions which are smaller than eighths are set off more or less by guess; but even this disadvantage

is not serious as there is a general shop rule that no drawing should be scaled for dimensions. The lower half of Figure 20 shows how the scale $\frac{3}{8}'' = 1'$ can be used to make drawings to three-eighth size.

Punch-Press Cover Plate. Figure 22 illustrates a cover plate used on a punch press. The drawing should be made in

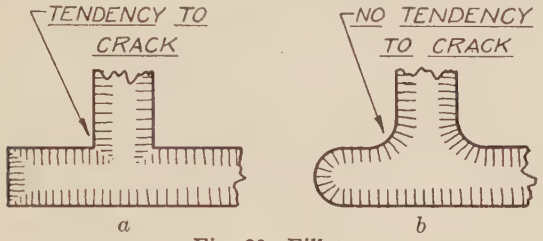


Fig. 23. Fillets

three views, according to the method described above, to a scale of $\frac{3}{8}'' = 1''$. In each of the three views, particular attention should be paid to the hidden lines, as there is a tendency to run the hidden lines to the wrong surfaces.

Fillets. Cast iron, in the process of solidifying, draws away from the edges of the mold and forms in crystals which lie perpendicular to the surface. This results in a very weak bond

Fig. 24. Drawing a Fillet With Surfaces Perpendicular

between the crystals, in places where there are sharp corners on the casting (Fig. 23, *a*), thus causing cracks or "checked" castings. For this reason, the outside corners of the patterns are rounded, and the inside corners are filleted (Fig. 23, *b*). The tendency of iron to form crystals is illustrated in a somewhat diagramatic fashion in Figure 23, *a* and *b*. Fillets are made to any desired radius, and are usually left to the discretion of the patternmaker. They are very seldom dimensioned on the drawing unless they are large.

Drawing Fillets. In drawing a fillet, the draftsman sets the compass at the desired radius, placing the point at the intersection of the two surfaces and draws an arc which intersects both lines. From these intersections two arcs are drawn, intersecting at a point from which the fillet is finally drawn. In geometrical construction, this would be referred to as drawing a tangent to two lines intersecting at right angles. The four steps are shown in Figure 24.

When the surfaces to which the fillet is to be drawn are not perpendicular to each other, a slightly different method must

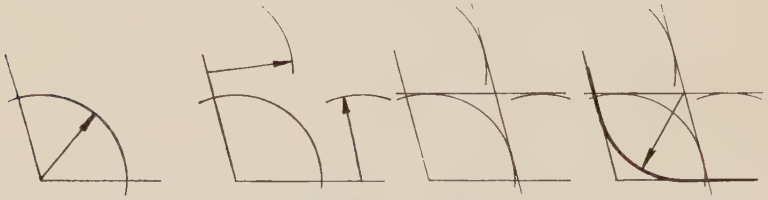


Fig. 25. Drawing a Fillet With Surfaces Not Perpendicular

be used. The first step is the same as before, an arc drawn from the intersection of the two surfaces. (See Fig. 25.) Next, two arcs are drawn from points a little beyond each of the intersections made by the first arc. Third, lines are drawn tangent to these last arcs and the first arc. The point at which these lines intersect is the center point for the radius of the fillet.

The foregoing methods show how the center from which the fillet is to be struck can be located theoretically. In practical work, however, the draftsman locates the center by the cut-and-try method. A little practice will show the beginner how easily this can be done.

Use of the Triangles. An angle is the amount of opening between two intersecting lines. Its unit of measure is the degree, which is the amount of opening between two radii of the same circle, when these two radii intercept $\frac{1}{360}$ part of the circumference. Thus, an angle which was made by two lines intercepting $\frac{45}{360}$ of a circle would be an angle of 45 degrees, and in mechanical drawing would be written thus: 45°.

An angle is, in reality, a fraction of a circle, and as such, is

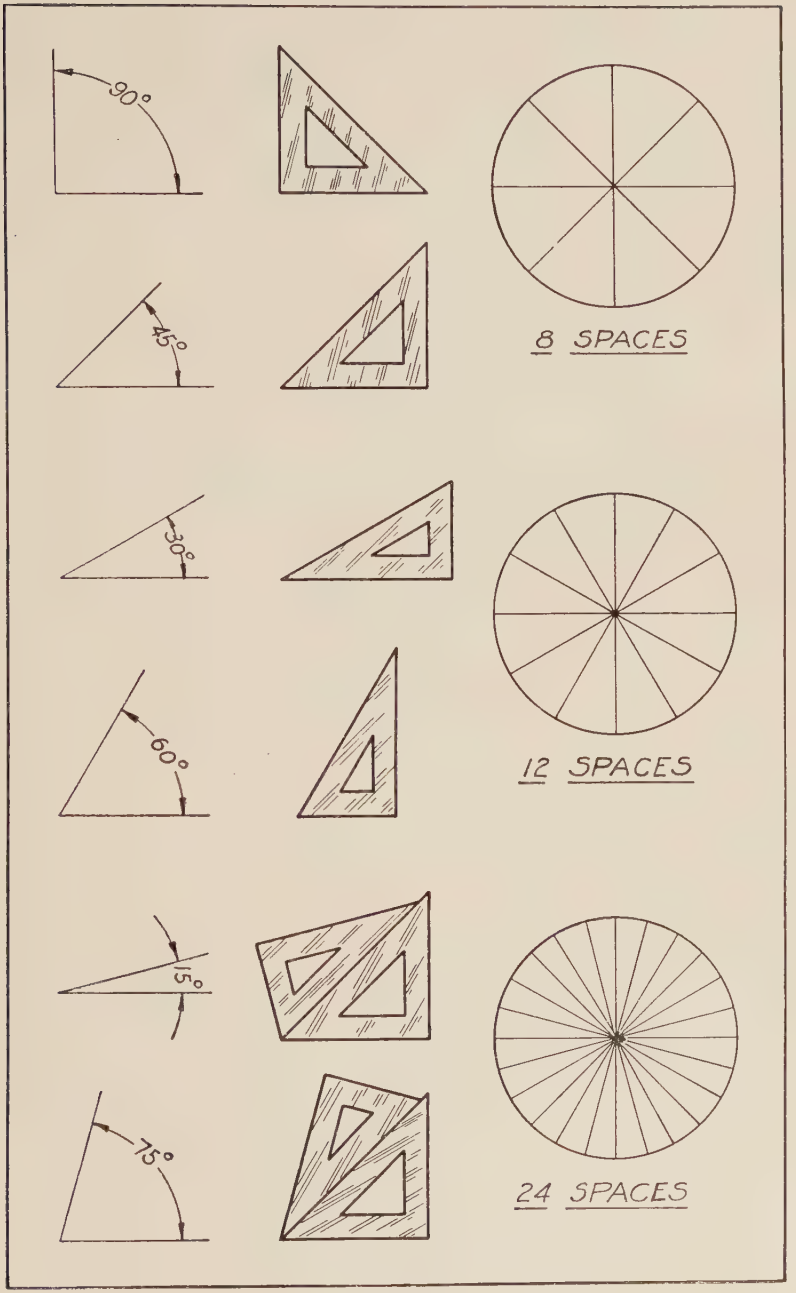


Fig. 26

used a great number of times daily by every draftsman. The number of divisions of the circle most commonly used in drawing are 4, 6, 8, 12, and 24. Considered in degrees, these would be angles of 90°, 60°, 45°, 30°, and 15° respectively.

The two celluloid triangles which make up part of the drawing equipment are named from the number of degrees in their

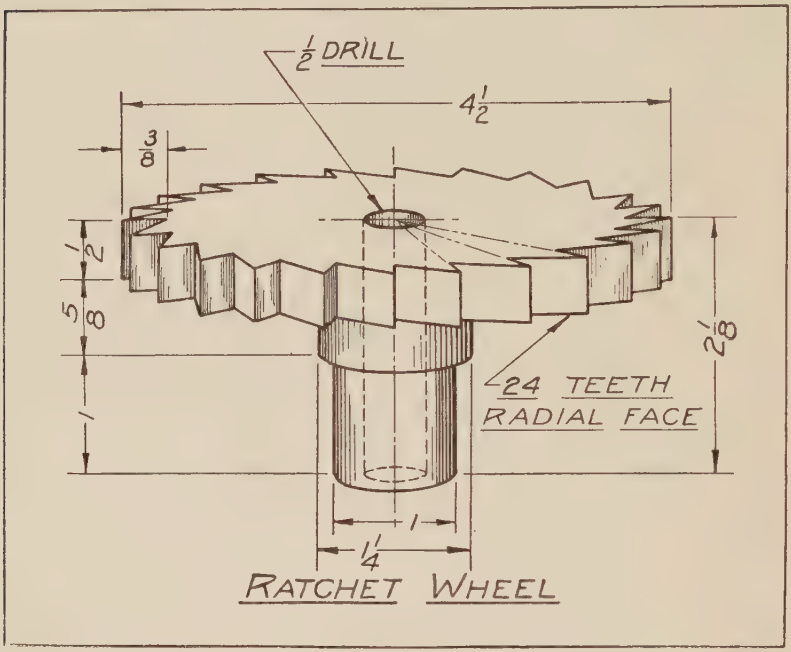


Fig. 27

acute angles. Thus, one of the triangles is called the 45° triangle, while the other is the 30° by 60° triangle.

Figure 26 explains better than words can the positions of the triangles for dividing a circle into any of the above mentioned number of parts. It also shows how to secure any of the angles which can be obtained by the use of these triangles, singly or in combination with each other.

Degrees, Minutes, Seconds. For very accurate work, the degree is divided and subdivided in exactly the same way as is

the hour of the day, that is, into 60 minutes, and each one of these into 60 seconds. The symbol used in expressing minutes is (′), while the one used for seconds is (″). Thus an angle of 36 deg., 45 min., 20 sec. is written 36° 45′ 20″.

Chapter VIII, on the solution of triangles, takes up the discussion of angles in greater detail. Three problems are here

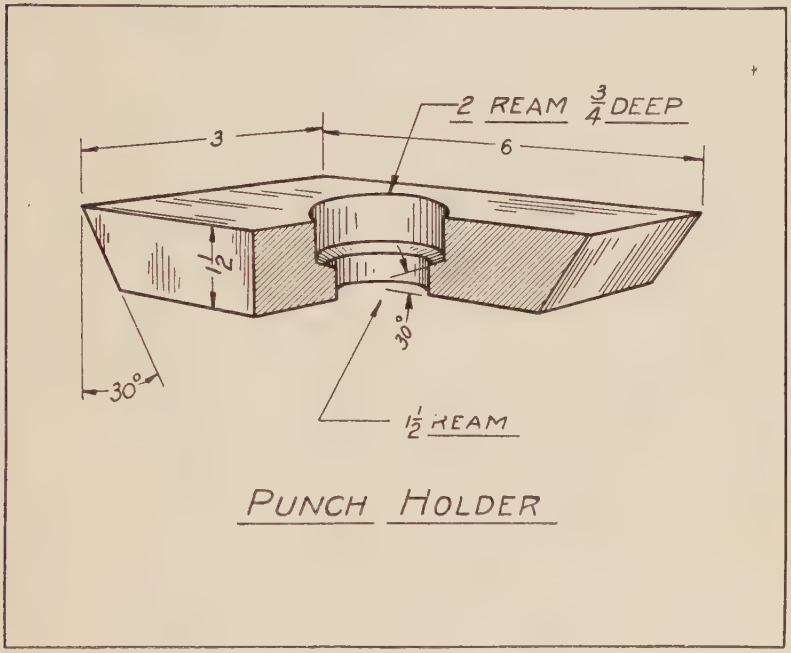


Fig. 28

given, each one of which will deal with either the division of the circle into a certain number of parts, or with the use of an angle of a given number of degrees.

The Ratchet Wheel. The ratchet wheel, illustrated in Figure 27, has 24 teeth, each tooth having a radial face, that is, the front of the tooth lies along a line which runs through the center of the circle. Figure 26 can be referred to for the division of the circle into the correct number of parts.

The drawing can be made on an A-size sheet. All the hidden lines should be shown in the top and front views.

The Punch Holder. Figure 28 illustrates a part from a power punch press, called a "punch holder." It has sides which slant at an angle of 30° with a line drawn through the center of the piece. The hole through the center is $1\frac{1}{2}''$ in diameter, enlarged at the top by counterboring to 2", in order to receive

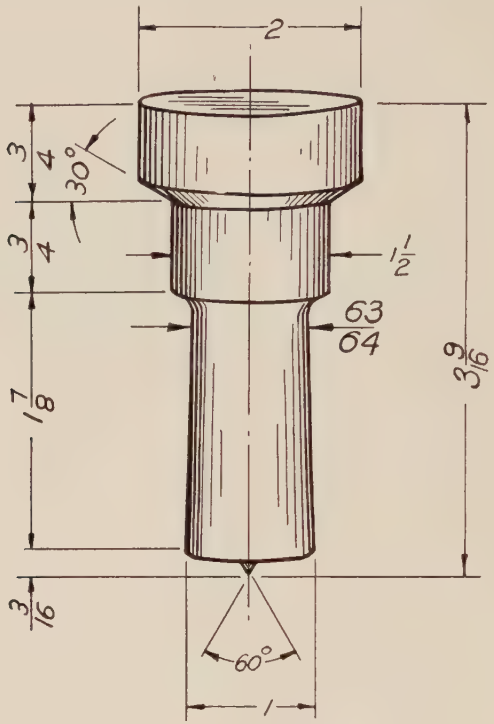


Fig. 29. Punch

the head of the punch. The place at which the counterbored part meets the $1\frac{1}{2}''$ section is tapered at an angle of 30° with the lower surface of the piece.

The drawing of the punch holder should be made on an A-size sheet, and should consist of a top and a front view of the piece.

The Punch. The punch, illustrated in Figure 29, is the one used with the holder just drawn and, of course, also involves the same angle as the one in the hole of the holder.

Top and front views should be drawn on an A-size sheet.

CHAPTER III

SECTIONS AND AUXILIARY VIEWS

At times the drawing of a machine part cannot be made sufficiently clear by the use of object and hidden lines alone, and some other method of presentation becomes necessary. Many parts of machines are so complicated that it is almost impossible to read the drawing unless some method is used to

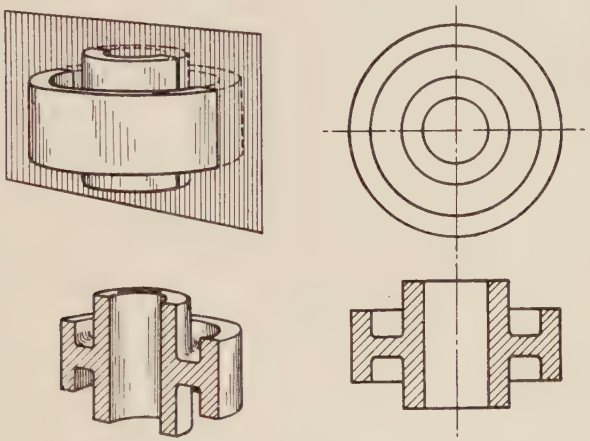


Fig. 30. Cutting Plane

show the internal construction unobstructed by other lines. The confusion of object and hidden lines in such cases can be overcome by the use of what is known as the "sectional" view.

Imaginary Cutting Planes. An imaginary cutting plane is passed through the piece, at the point where the internal construction is to be shown, and all parts of the piece which lie between this plane and the draftsman are removed. When the remainder of the piece is drawn, it appears as though cut into

two parts. Indication must also be made on the drawing where the plane passed through the material, and where it passed through a hole and not through the material. This is done by drawing, on the parts cut, closely spaced parallel lines, ordi-

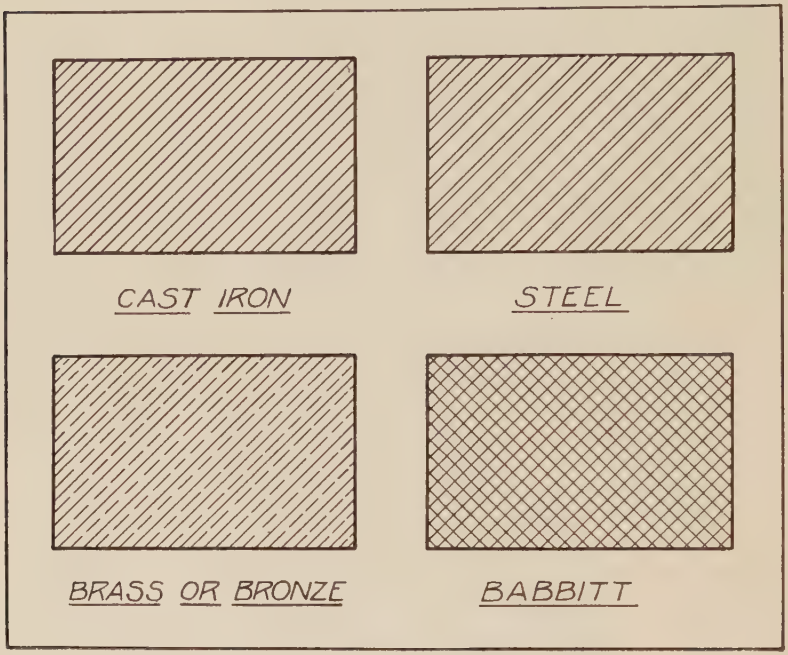


Fig. 31

narily drawn at an angle of 45° from the horizontal lines of the drawing, but never parallel to any one side.

Figure 30 illustrates clearly the method of obtaining a sectional view. The first sketch shows the object with the cutting plane in place. The second shows the object with the plane and the part which was in front of the plane, removed. Where the plane actually passed through the material the surface is shown sectioned with parallel lines, as noted above.

At the right is a mechanical drawing of the piece, showing the top view in full and the front view in section.

Indication of Material. It is often desirable to cross-section

a piece in such a way that the drawing itself will indicate from what material the piece should be made. This is especially true of drawings upon which more than one piece is shown, such as assembly drawings. However, the type of cross-sectioning should not be depended upon to determine the kind of material, but a very specific note should be added, designat-

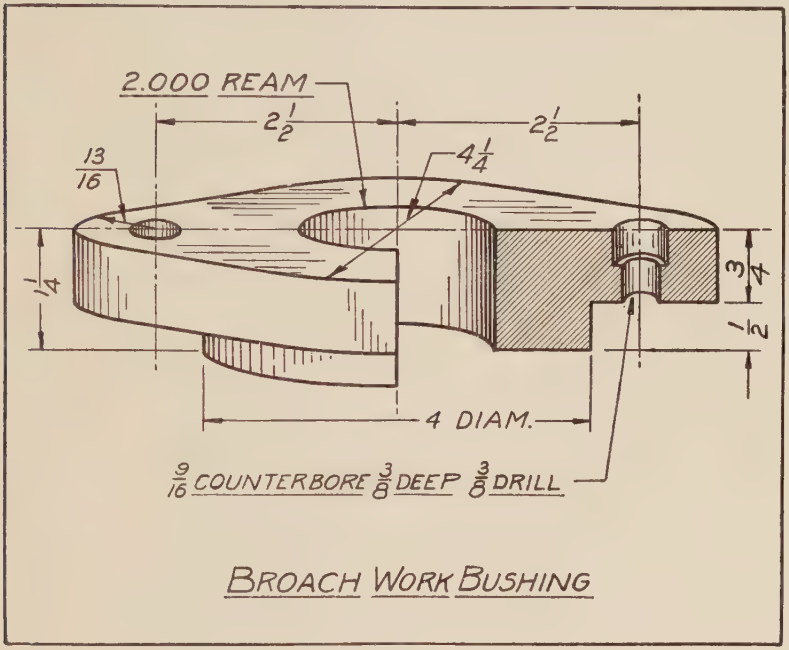
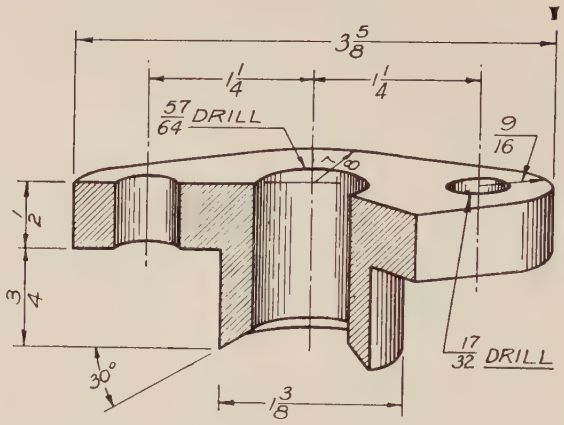


Fig. 32

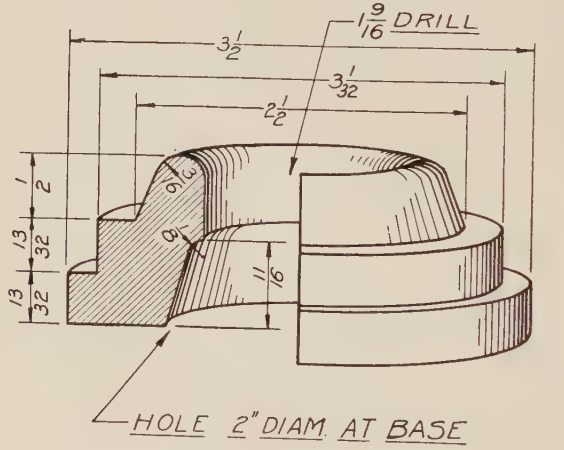
ing the material. Some manufacturers require all cross-sectioning done in the same way, and then state on the sectioning, or in the bill of materials, the material from which the piece is to be made.

There are four types of cross-sectioning which have become so well established that they are considered standard. These four are for cast iron, steel, brass or bronze, and babbitt. Figure 31 illustrates these four types of cross-sectioning.

Half Sections. A view is called a "half section," when it shows the object as though it had been cut into two equal parts. Figure 32 shows a broach-work bushing, with a part of



VALVE PACKING GLAND



VALVE SEAT

Figs. 33 and 34

the piece cut away to illustrate the shape of the holes in the ends.

Broach-Work Bushing. The drawing of this piece should be made so as to show a top view, as usual, and a front view in section. The imaginary cutting plane should be assumed to go through the piece on the center line of the three holes. The

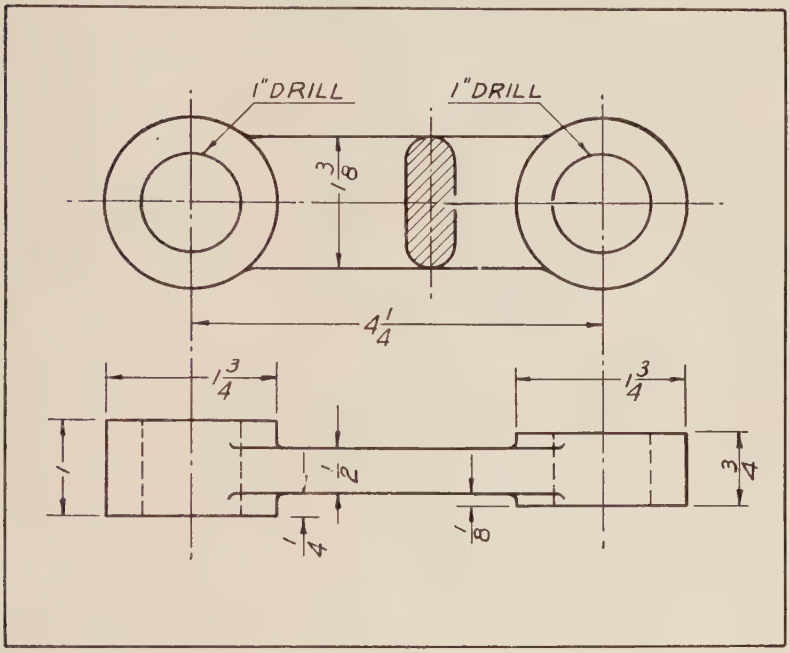


Fig. 35

front view will then be drawn as the piece would appear when the cutting plane and that part of the object in front of it were taken away.

Valve-Packing Gland. The valve-packing gland, illustrated in Figure 33, is one in use on a valve of which all the parts are to be drawn as the course progresses. The gland is to be drawn in the same way as was the previous problem. It brings into use again the angles discussed in the previous chapter.

Both of the drawings just considered should be drawn on sheets which the student finds to be the right size, after de-

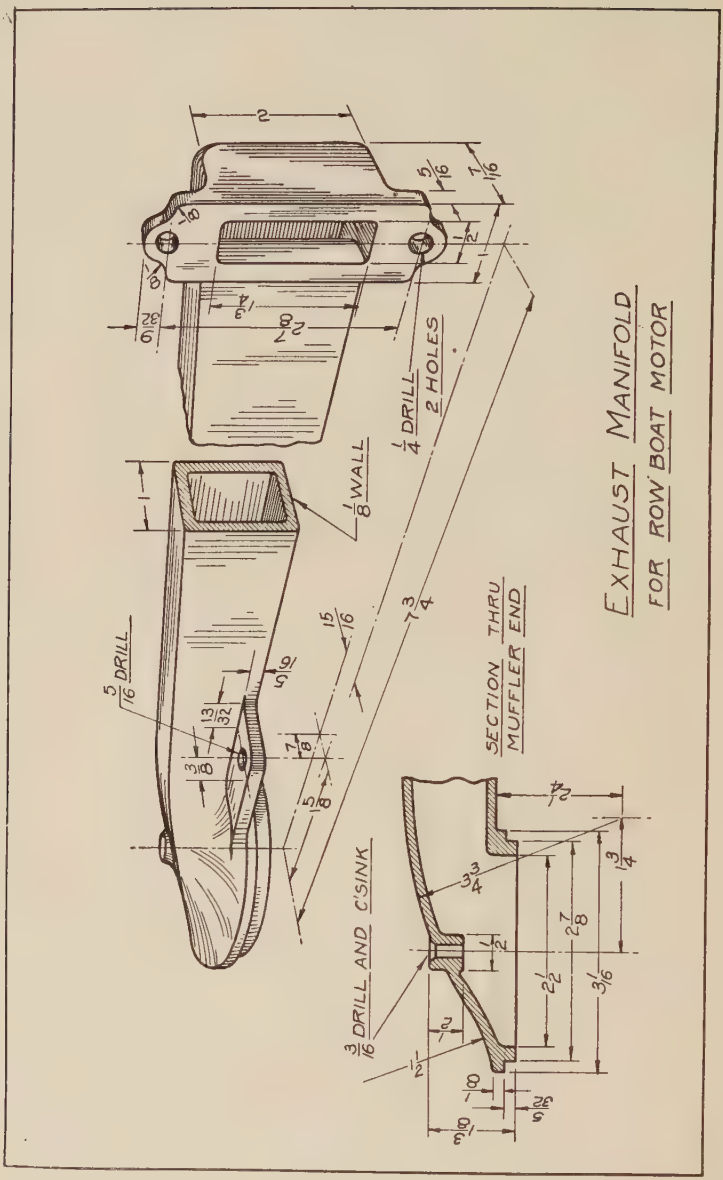

EXHAUST MANIFOLD
FOR ROW BOAT MOTOR
SECTION THRU MUFFLER END
1/4 DRILL 2 HOLES
1/8 WALL
5/16 DRILL
3/16 DRILL AND C'SINK

Fig. 36

termining the amount of room required for the two views. This will be understood to be the case henceforth in all drawings, unless the size is specified.

Quarter Sections. A quarter-sectional drawing is intended to show that only one fourth of the piece has been removed. In this type of sectional view, one side is shown in full while the other side is sectioned.

Valve Seat. As a problem to be drawn in quarter section, the valve seat, Figure 34, is suggested. In the front view, either the right side or the left side may be shown in section, while the other side is left in full.

Revolved Sections. Figure 35 is a mechanical drawing of a connecting link. It is used to show the possibility of eliminating a view, by what is known as the "revolved" section. The sectional view placed on one of the views, shows what the cross-sectional shape of the piece is at that particular point. Without this sectional view, it would be necessary to make a third view of the piece, which also would be undesirable as it would show the part under consideration in hidden lines. If both the extra view and the sectional view were omitted, the shape could be considered rectangular, elliptical, or with rounded corners, as in the illustration.

Broken Sections. It is not necessary to section a whole view, if only a part of the piece requires sectioning in order to make the construction clear. An irregular or "broken" line is drawn to separate the part to be sectioned from the rest of the piece, and the view is sectioned only to this line. The remainder of the view is drawn as usual, including all hidden lines.

Exhaust Manifold. The piece shown in Figure 36 is the exhaust manifold from an outboard motor, and is suggested as a problem to be used in illustrating both the revolved and the broken section. The rectangular part may be shown as a revolved section, by breaking out a part of the front view and placing in the revolved section.

Partial Sections. A partial section is in reality only a part of a view, and that part is shown in section. It helps out the main views of the drawing.

Such a view does not have to be placed on the drawing in its

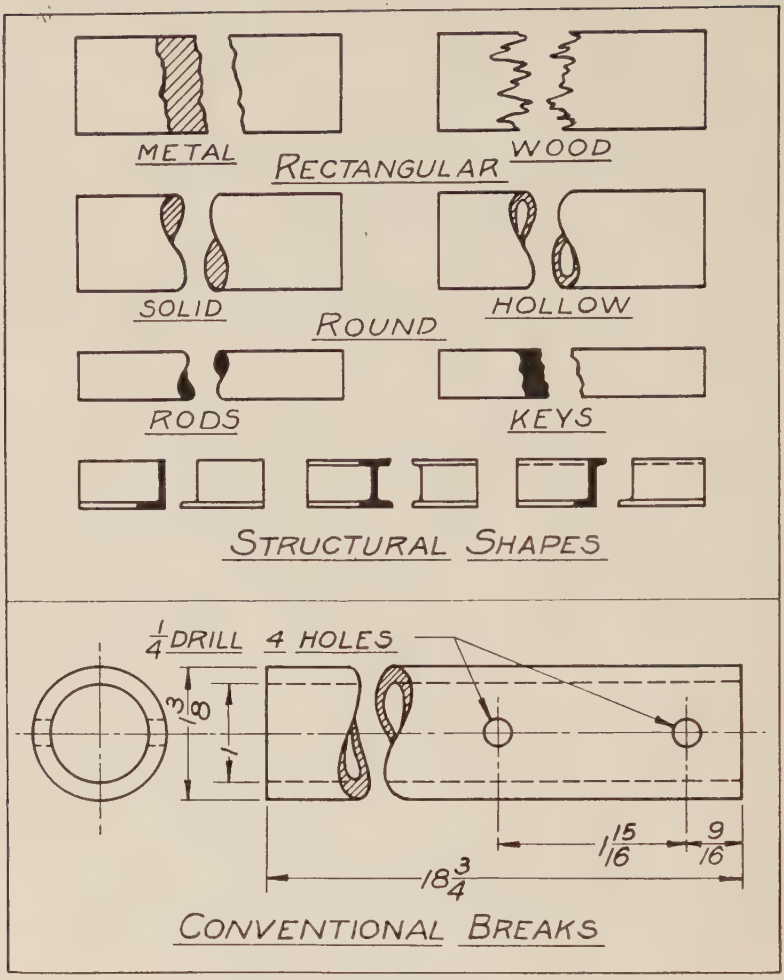


Fig. 37

proper relation to the other views, as noted in the first chapter, if a note is added to indicate where the view is taken. An illustration of this kind of view is given in Figure 36, showing one end of the exhaust manifold.

Conventional Breaks. In machine construction many parts are of uniform cross-section for a considerable distance, as for instance, shafting, tubing, bars, pipes, rods, and various shapes of structural steel.

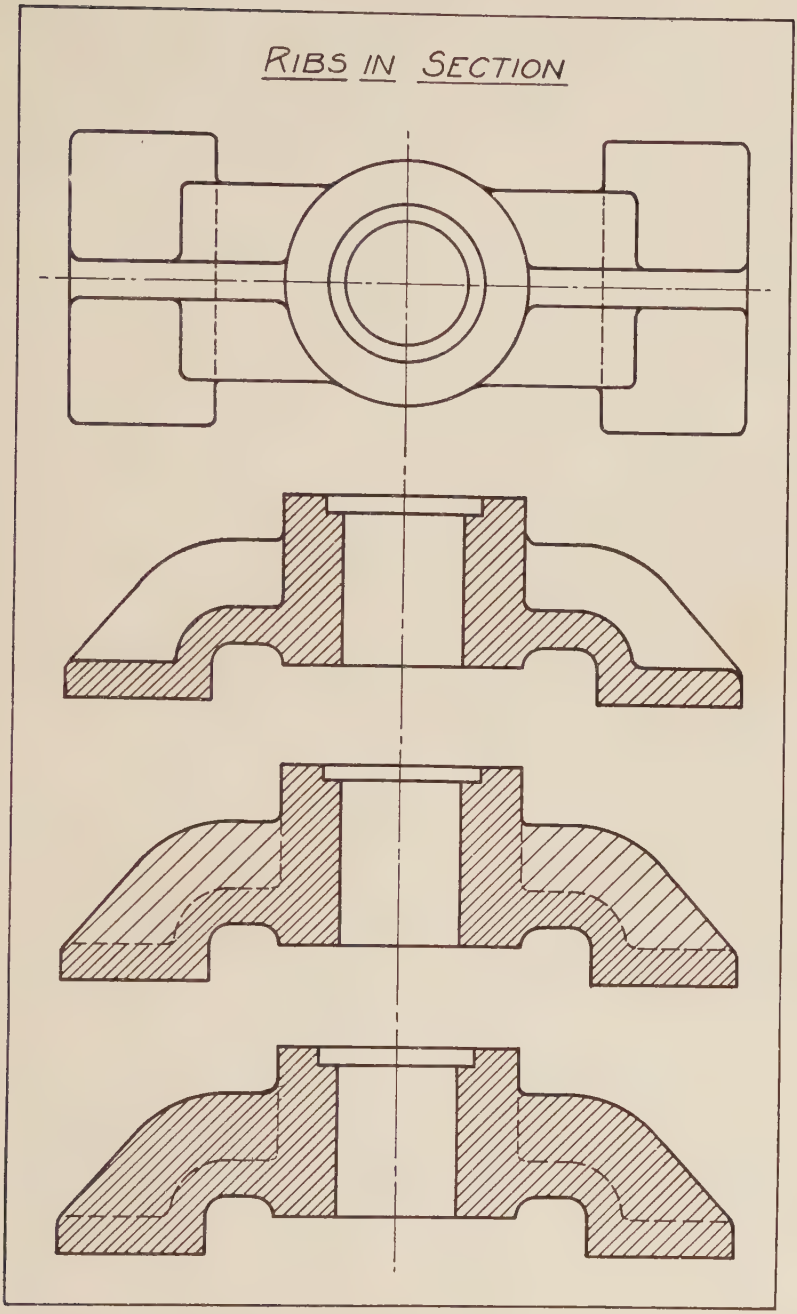


Fig. 38

As a rule, these pieces are so long that they must be drawn to a very small scale, if the whole part is to be shown. To overcome this, the pieces are drawn "broken"; that is, both ends are drawn with a section left out of the middle. This brings the ends closer together and, as a result, a larger scale than before is possible. These breaks have become conventionalized to such an extent that they are considered standard. Several of the most important of these breaks are illustrated in Figure 37, with an example of how such a break is used on a working drawing. If this same piece were to be drawn without the use of the break, the sheet of paper required for it would have to be much larger.

No problem involving the use of a conventional break is given here, as there are many instances of its use in the following problems.

Ribbed Sections. In order to give a casting increased strength, it is often necessary to reinforce it with ribs. The same method is used in making castings lighter in weight without materially reducing their strength. A difficulty often arises when ribbed castings are to be drawn, and a rib happens to fall in the plane of a desired sectional view. To follow the true projection would give the impression that the casting is solid, when this is not actually the case.

In order to get around this difficulty, it is necessary to vary from true projection, and to show the sectional view as though the plane of the section were lying in front of the rib instead of through it.

This method of indicating a rib is illustrated in the upper one of the three front views in Figure 38. It is the generally accepted method of drawing ribs which happen to fall in the plane of the section. Two other methods are shown in the same figure. The first of these shows an outline of the ribs in hidden lines, and the other the ribs themselves sectioned with every alternate line. The last and least used method is the one at the bottom, in which the outline of the rib is in hidden lines and the sectioning is made uniform over the entire surface.

Lathe Faceplate. The 12″ faceplate with the ribs running along the back of the T slots, illustrated in Figure 39, is a

good example of how such ribs can be shown in section. The views necessary for the best representation of the piece are a top view, a sectional front view, and a partial section through one of the T slots. This last view will show only the shape of the slot, the metal surrounding the slot, and the rib up the center of the back.

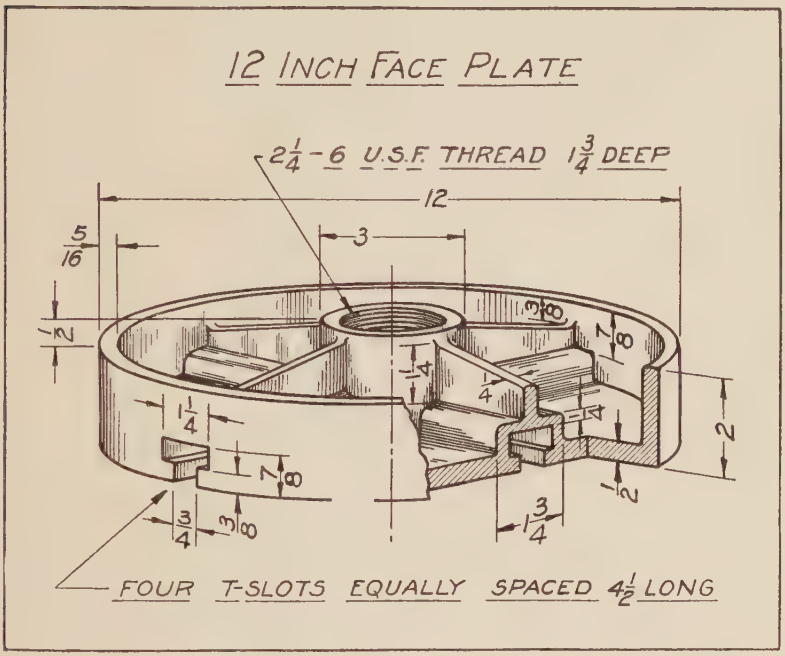


Fig. 39

The drawing should be made on a B-size sheet to one-half scale. The partial sectional view may be made full size, if desired.

Parts Not Sectioned. It is customary not to section such machine parts as shafts, rods, pins, screws, keys, spokes, pulley arms, and gear and sprocket teeth, when the long axes of any of these parts lie in the plane of the section. For spokes, pulley arms, and gear or sprocket teeth, the reason is the same as in the previous case. It gives a false impression of

solidity, while nothing is ordinarily gained by sectioning any of the other parts. However, when the long axis does not lie parallel to, and in, the plane of the section, but perpendicular to, or at an angle with the plane of the section, then the sectioning is done as usual.

Valve Handwheel. Figure 40 shows a valve handwheel, which should be drawn in two views. The top view should be made in full, while the front view should be a sectional view,

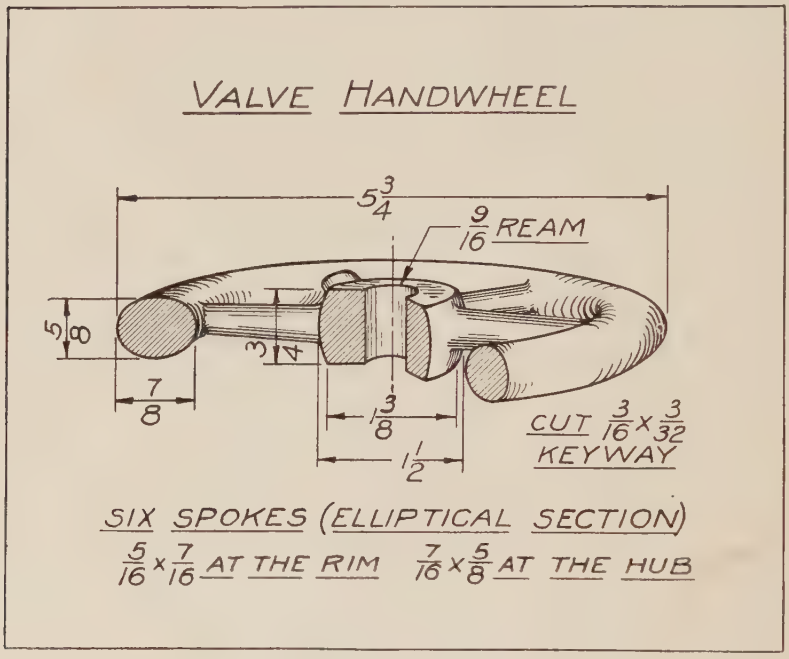


Fig. 40

so chosen that the plane of the section lies through two of the arms of the handwheel. These arms should be drawn as was just explained. The rim is elliptical in shape and can be drawn with sufficient accuracy by the use of an irregular or French curve.

Construction of an Ellipse. On a small piece of paper having one straight edge, measure off the major (long) radius,

and from one end of this distance also measure off the minor (short) radius. Lay this edge of the paper on the drawing, so that the point found by measuring off the major radius always lies on the minor axis line and the other point on the major axis line. By moving the paper from one position to another, always keeping the points on the axes, the third point will describe the ellipse. Points may be located at various intervals along the path of this point and, when a sufficient number of

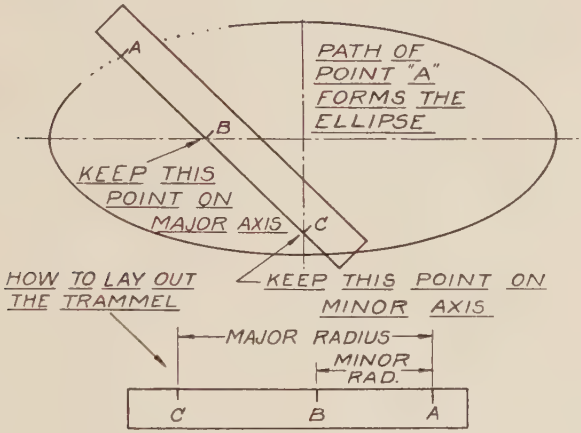


Fig. 41. Ellipse Drawn by Trammel Method

places have been marked off, the ellipse can be drawn through them by the use of a French curve. Figure 41 illustrates this method of obtaining a correct ellipse. It is called the "trammel" method.

Change of Plane. Sometimes, it is desirable to show a section through two or more parts of an object, when these parts do not lie in the same plane. In such a case, it is permissible to change the plane of the section to make it take in those parts which are to be shown. The other view must show by a definite line the course which the plane of the section takes. This is usually done by indicating the plane by a dash-and-double-dot line. In the drawing of the piston, shown in Figure 42, note the line marked ABCD. The corresponding view is also marked Section ABCD. Note, also, that for a part of the

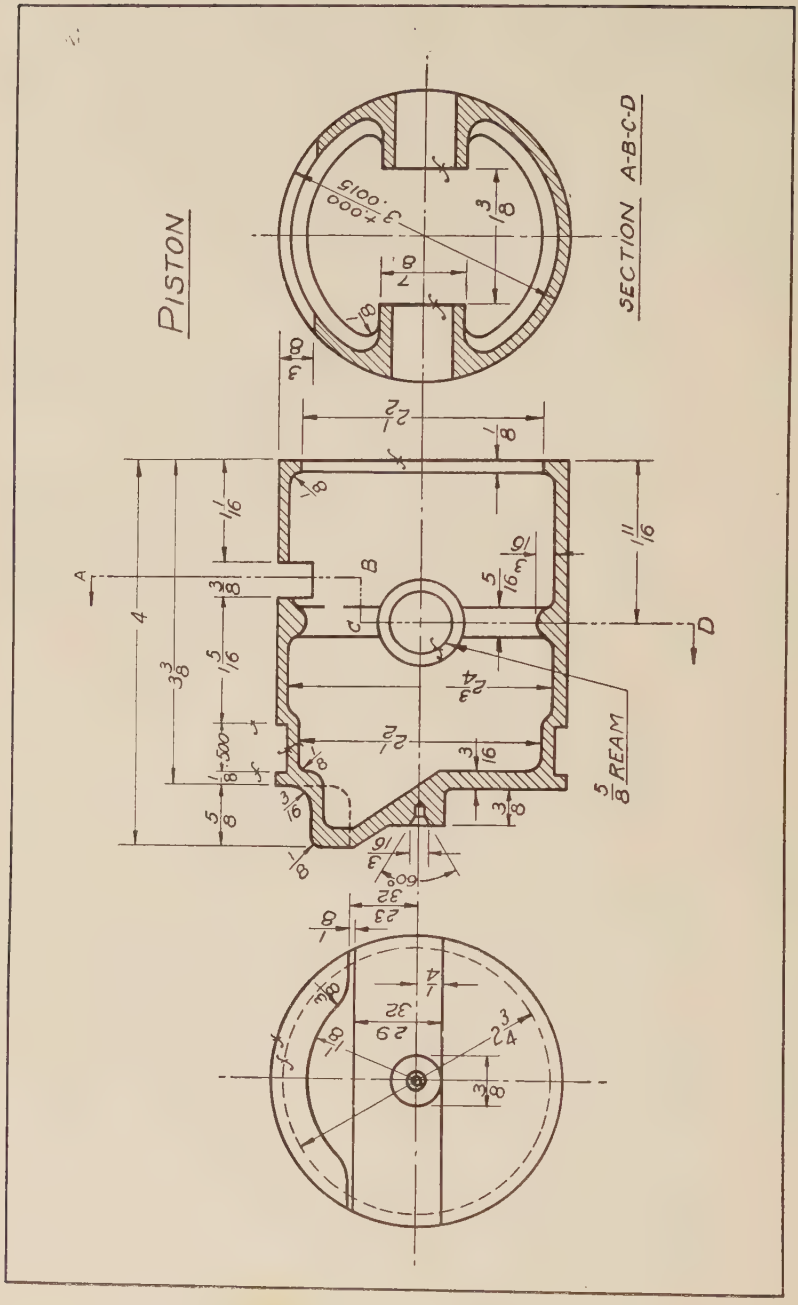


Fig. 42

distance, the plane of the section lies in a rib, and that in the other view this rib is not sectioned.

Variations From True Projection. As in the case of the ribbed section, the true projections are sometimes misleading in other ways. This is particularly true of pieces which are symmetrical about an axis, but not about any one plane of

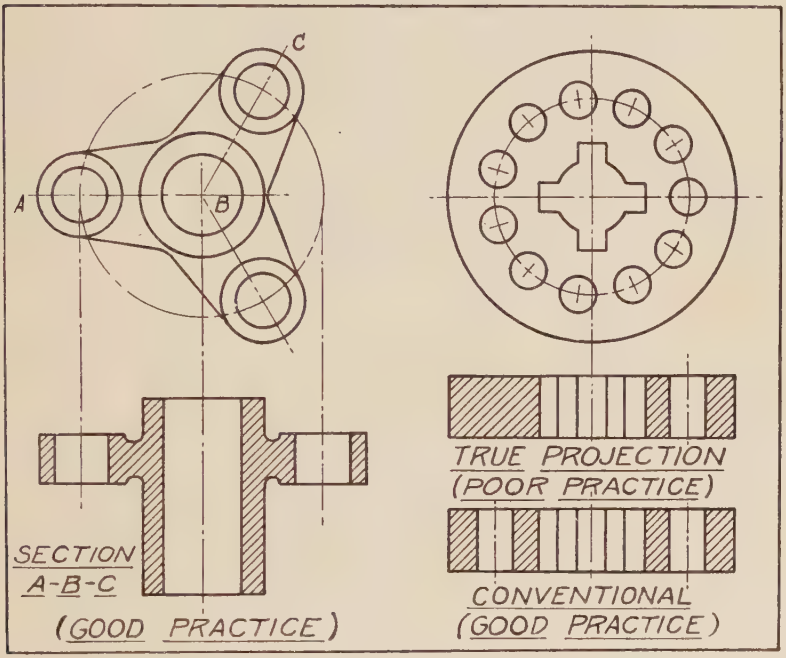
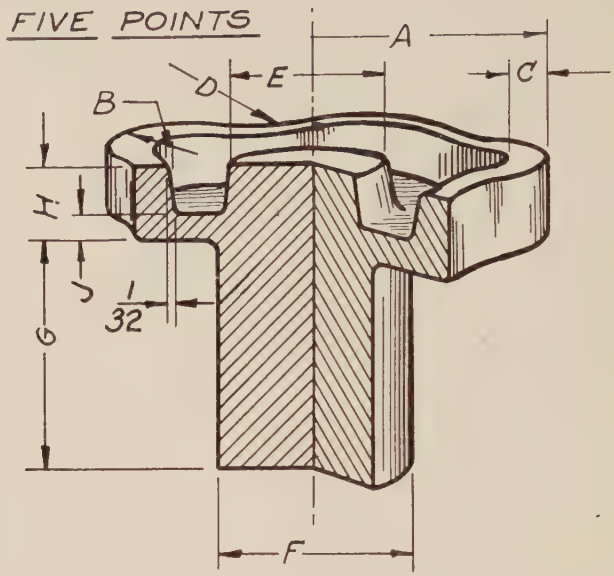


Fig. 43

the section, such as a pulley which has an uneven number of spokes, or a circular plate which has an uneven number of holes equally spaced on a circle. A true section would be misleading in that it would be unsymmetrical, while the object is known to be symmetrical. In drawing an object of this kind, the plane of the section is revolved to include the symmetrical parts or to bring the holes in line. This method of drawing a symmetrical section is illustrated in Figure 43.

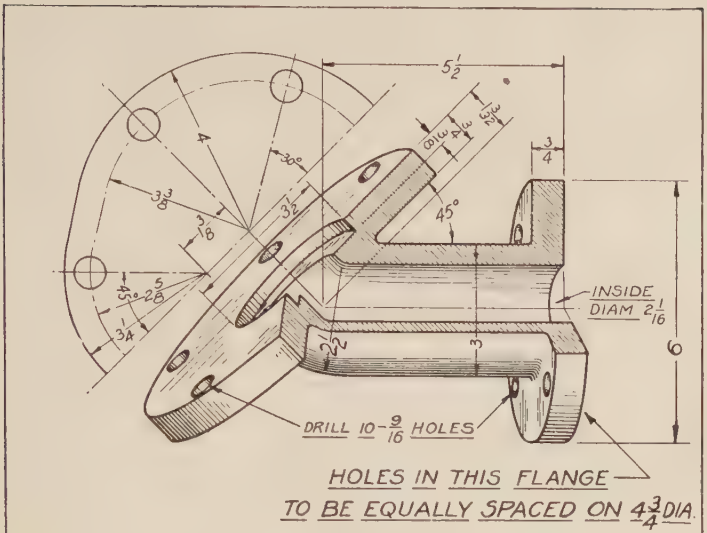
Five-Pointed Hand Nut. Figure 44 illustrates the standard



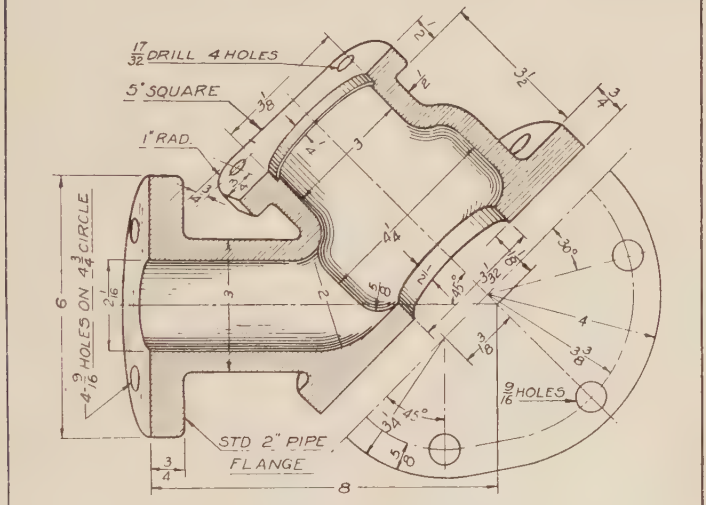
A	B	C	D	E	F	G	H	J
7/8	1/4	3/32	1/4	5/8	1	1 1/8	3/8	1/8
1	5/16	1/8	5/16	13/16	1	1 3/8	3/8	1/8
1 1/8	3/8	1/8	1/2	1 1/8	1 1/8	1 5/16	7/16	1/8
1 1/4	7/16	1/8	7/16	1	1 1/4	1 7/16	7/16	1/8
1 1/2	9/16	3/16	9/16	1 1/8	1 3/8	1 1/2	1/2	3/16
2	11/16	3/16	11/16	1 3/8	1 5/8	1 9/16	9/16	3/16

Fig. 44

hand nuts used by the Continental Motors Co. in tool and jig design. The hand nuts are five pointed. The dimensions for six different sizes are given in the table below the illustration. The dimensions for any particular size may be substituted for the letters and the drawing made accordingly.



VALVE BODY (LOWER HALF)



VALVE BODY (UPPER HALF)

Figs. 45 and 46

In making the drawing, two views will be found necessary, a top and front sectional view; or, both views may be made in full if so desired. The five points are more easily spaced off by trial with the dividers than by geometrical construction. Draw the top view in a position in which the center line of one of the points will fall on the horizontal center line of the view.

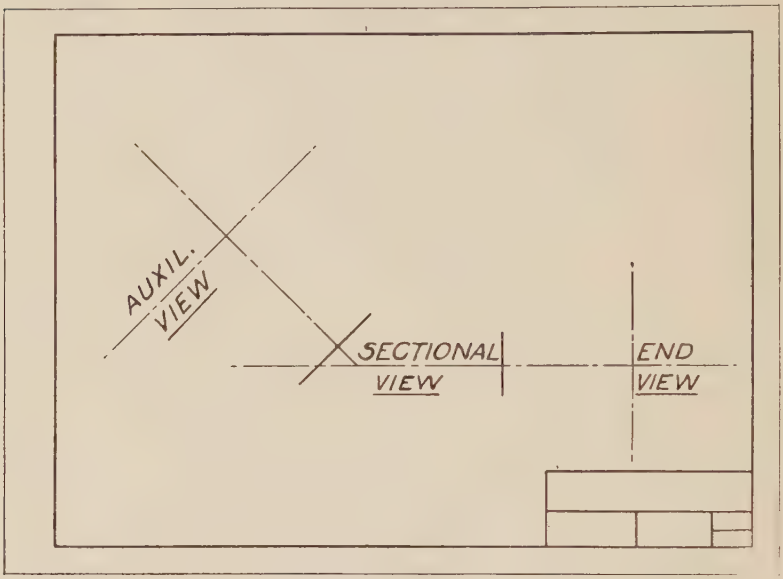


Fig. 47

The same side of the front view can then be projected from the top view and the other side can be drawn symmetrical to it.

It is suggested that all the students do not work from the same set of dimensions, but that each one be assigned to draw a certain one. This will give some variation to the drawings, and show the relative sizes of the hand nuts.

Auxiliary Views. Auxiliary views, as the name implies, are used to help out the other views of the drawing, so that they will be less difficult to read.

The necessity for an auxiliary view arises when there is a surface on the object which does not lie parallel to any one of the previously mentioned planes of projection. If only the

top, front, and side views are used, the drawing will not show such a surface in its true shape, as it will always be foreshortened in at least one direction. To locate holes on a surface in this position is no simple matter for an experienced draftsman, and to the machinist it offers a real difficulty in attempting to interpret the drawing.

Auxiliary Plane. An auxiliary view necessitates an extra or auxiliary plane upon which to project this surface so that it will appear in its true shape. The assumed plane must lie parallel to the surface which it is desired to project. It is also to be revolved about its intersection, with the vertical plane in the same way as were the horizontal and profile planes in the first chapter.

Angle Valve Body (Lower Half). In order to illustrate clearly the use of auxiliary views, draw the parts of an angle valve. The first of these is the lower half of the body of a casting having on one end a standard pipe flange, and at the opposite end another flange (not circular in shape) which lies at an angle of 45° to the center line of the pipe. It is illustrated in Figure 45.

The best method of drawing this piece is to make an end view of the pipe flange, a sectional view of the side, and a third view of the other end, which will be an auxiliary view. The drawing should be made on a B-size sheet, with the relative positions of the views as given in Figure 47.

Angle Valve Body (Upper Half). The other half of the valve body is somewhat similar to the first, but more complicated in that it has a surface to which the bonnet must be bolted. This surface is parallel to the other or lower side of the body, and an auxiliary view of this must also be made. For this drawing, a C-size sheet is suggested, although it is possible to draw it on a B-size sheet by making only half of one of the auxiliary views. The relative location of the views for this drawing must be determined by the student. The illustration of the upper half of the valve body is given in Figure 46.

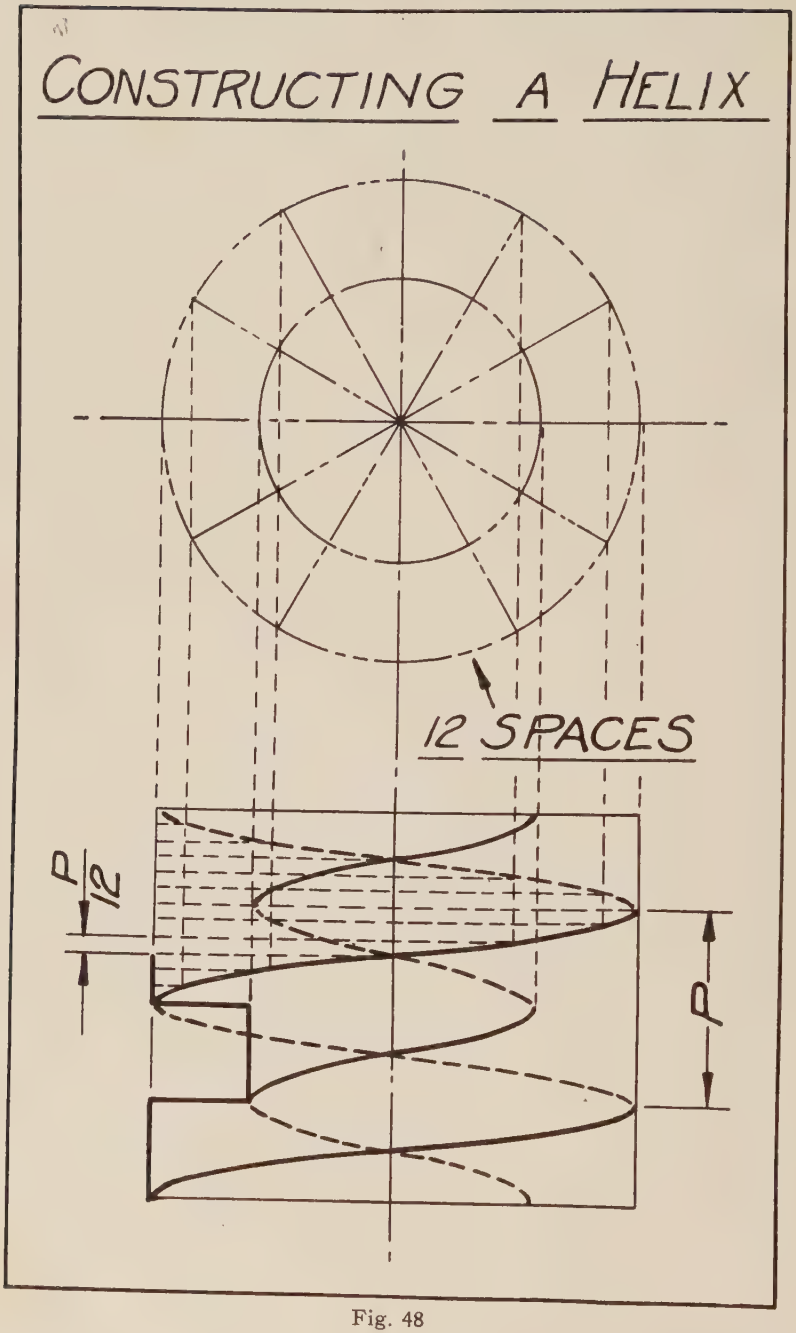


Fig. 48

CHAPTER IV

SCREW THREADS

Use. Screws play a very important part in machine construction. They are used primarily for fastening parts together, but they are also to transmit motion, to change rotary to straight-line motion, to regulate speeds, and to keep various machine parts in proper adjustment.

Formation of a Thread—the Helix. A thread is formed by cutting a groove in a cylinder in such a way that it travels around the cylinder and at the same time moves at a uniform rate along the axis. The curve generated by this combination of movements is called the "helix," and is developed or drawn in the manner shown in Figure 48. Both the point at the outside of the thread and the point at the inside form a helix, have the same lead or forward movement in one revolution, although their diameters are not the same.

Thread Profiles. There are four forms of threads, which stand out in importance above all the others in use. These four are the Square, the United States Standard, the Acme, and the Worm threads.

Only on rare occasions are threads shown in mechanical drawings as they actually appear, because it is so difficult to lay out the curve for each thread. A great loss of time would be involved in attempting to develop the helix for each thread which a draftsman is required to draw. In order to save a portion of the time required to draw threads, conventional methods of thread representation have been established, illustrated in Figures 49, 50, 51, and 52.

Square Thread. The simplest form of thread is the Square thread, illustrated in Figure 49. The actual appearance of the thread is given at the left, while the center illustration is the conventional method for drawing threads more than 1″ in diameter. The illustration at the right shows the conventional

method of representing threads less than 1″ in diameter. The form of the thread is such that the width of the thread, the width of the space, and the depth of the thread are all equal. The forward travel per revolution is called the "pitch." In this case, the depth of the thread is equal to one half of the pitch.

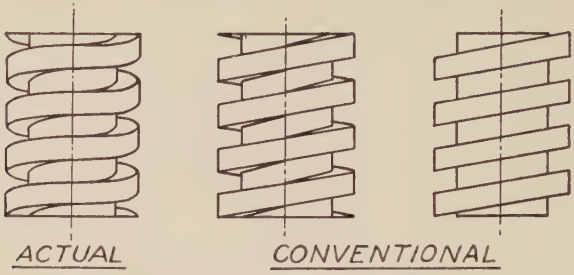


Fig. 49. Square Thread

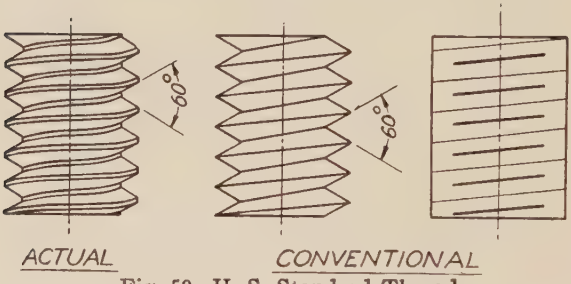


Fig. 50. U. S. Standard Thread

United States Standard Thread. The United States Standard thread is a modification of the sharp V thread, with the points at both the top and the root of the thread cut off for a distance equal to one eighth of the total height of the V. The United States Standard thread is illustrated in Figure 50. The one at the left shows the actual appearance; the one in the center is the convention for threads more than 1″ in diameter; and the one at the right, the convention for threads less than 1″ in diameter. When threads less than 1″ are drawn, the custom is not to take time to space accurately the correct number of threads per inch, but the draftsman guides himself by the appearance in assuming the slant for the lines and the

spacing. Each thread should be explained in a note which indicates the form of the thread, the diameter, and the number of threads per inch.

United States Standard threads have a certain number of threads per inch for each diameter, so that interchangeability will be possible. The number of threads for corresponding diameters is given in the following table.

U. S. STANDARD THREADS

Diam.	No. Thds.	Diam.	No. Thds.	Diam.	No. Thds.	Diam.	No. Thds.
1/4	20	1	8	2 1/4	4 1/2	4 1/4	2 7/8
5/16	18	1 1/8	7	2 1/2	4	4 1/2	2 3/4
3/8	16	1 1/4	7	2 3/4	4	4 3/4	2 5/8
7/16	14	1 3/8	6	3	3 1/2	5	2 1/2
1/2	13	1 1/2	6	3 1/4	3 1/2	5 1/4	2 1/2
9/16	12	1 5/8	5 1/2	3 1/2	3 1/4	5 1/2	2 3/8
5/8	11	1 3/4	5	3 3/4	3	5 3/4	2 3/8
3/4	10	1 7/8	5	4	3	6	2 1/4
7/8	9	2	4 1/2				

Acme Thread. The Acme thread, illustrated in Figure 51, is a modified square thread. The depth of the thread is equal to one half of the pitch, and the width of the thread and the width of the space are equal. However, they must be measured at the center point of the thread as the sides of the thread slant, making an angle of 29° with each other. The draftsman, in representing an Acme thread, does not attempt to make the angle correctly, but uses the triangles in combination to obtain an angle of 30°, or 15° on each side of the center line. This will leave an error of only half a degree, which is not noticeable on the drawing. In the illustration, the actual appearance of the thread is given at the left, and the conventional method and the form of the thread are given at the right.

Worm Thread. The Worm thread used in gearing is somewhat similar in appearance to the Acme thread. The sides of the Worm thread are at the same angle to each other as in the Acme thread, but the depth of the Worm thread is greater than the depth of the Acme thread, being equal to .688 of the pitch

instead of half the pitch. The point on the thread at which both the thread and the space are equal is not at the middle, but at a point .318 of the pitch from the top. Figure 52 illus-

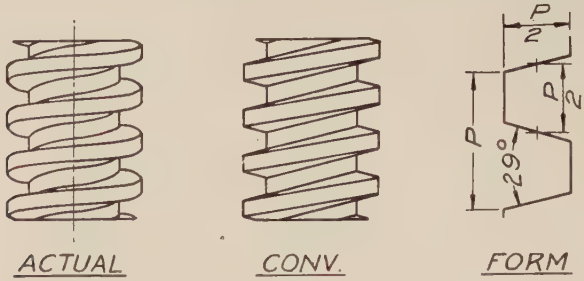


Fig. 51. Acme Thread

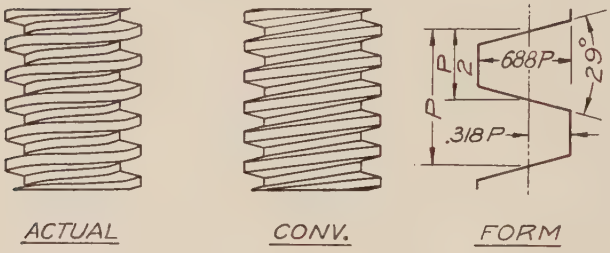


Fig. 52. Worm Thread

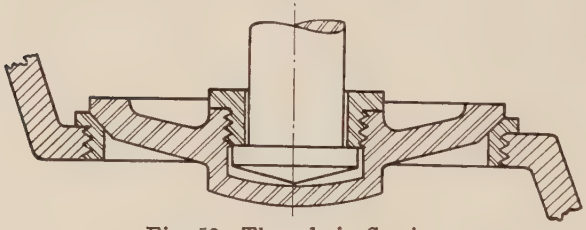


Fig. 53. Threads in Section

trates the actual appearance of the thread, the conventional method of representation, and the profile.

In all of the above threads, the end view consists of two circles, a solid circle for the outside, and a hidden circle for the root diameter.

Threads in Section. When it is necessary to show threads in section, the profile of the thread is always indicated regard-

less of the size of the diameter. This holds true for both detail and assembly drawings. Figure 53 illustrates the method of indicating threads in section.

Tapped Holes. In most machine parts, threaded holes are first drilled out, and then the thread is cut in with a tap. Consequently, threaded holes are usually referred to as "tapped" holes. There are several methods of indicating tapped holes on a drawing, and most of them are illustrated in Figure 54. The conventional method, shown at the left, seems to meet with the

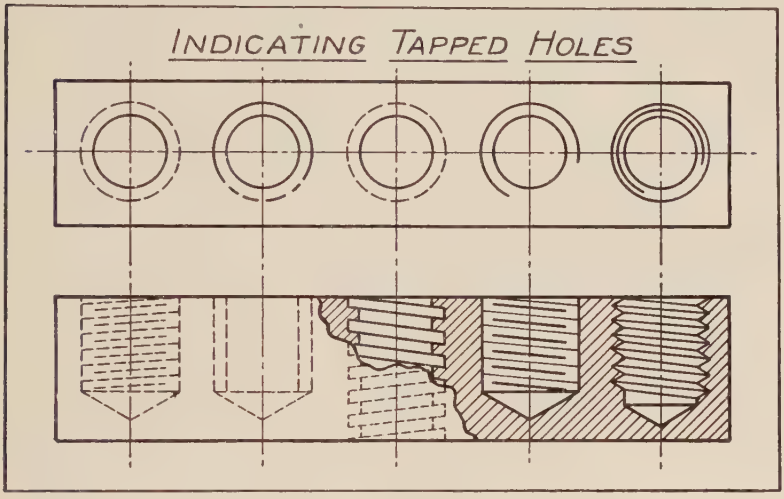
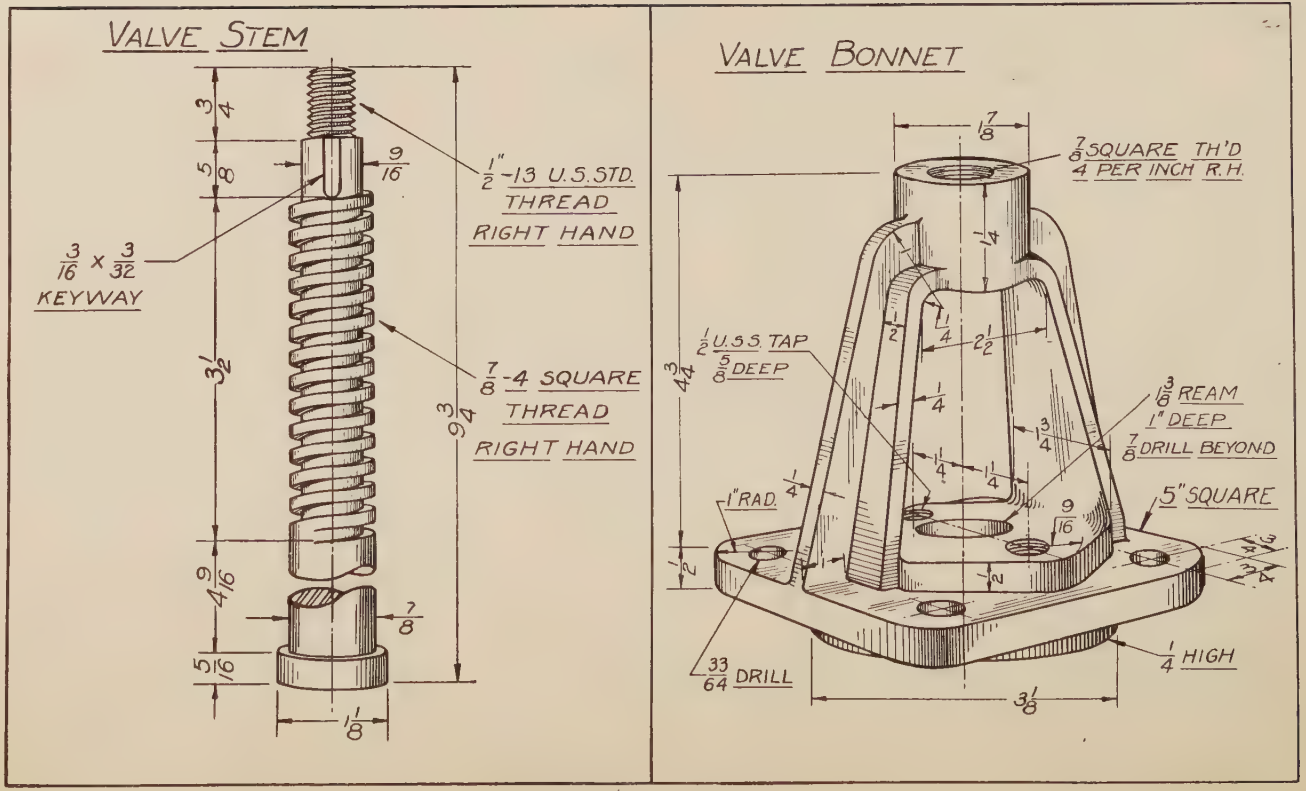


Fig. 54

most favor and is the one which is recommended for use. A question is often raised as to which is the best way to draw the end view of a tapped hole. A recent survey of the practice of a group of manufacturers brought out the information that 90 per cent of the companies which answered the questionnaire were using the method illustrated at the left in both the top and front views.

PROBLEMS INVOLVING SCREW THREADS

Valve Stem. Figure 55 illustrates a valve stem. This stem is a part of the valve of which all the details will be made as the course progresses. It involves the drawing of a square



Figs. 55 and 56

thread which is less than 1″ in diameter; therefore, the convention at the right in Figure 49 is to be used in indicating this thread. At the top of the stem is the thread which holds the nut that keeps the handwheel in place. This thread is a United States Standard thread also less than 1″ in diameter, and the convention at the right in Figure 50 is used.

As the stem is longer than an A-size sheet on which it is to be drawn, it will involve a conventional break. This break should be made in that part of the stem between the square thread and the base. The way in which this break should be drawn is shown in Figure 37. Thus, the part of the stem which is $4\frac{9}{16}$″ long and $\frac{1}{8}$″ in diameter will be shortened so that the end and front views may be drawn full scale. The draftsman must be very careful to place the original dimensions on the drawing, and not those to which they have been shortened.

Valve Bonnet. Figure 56 illustrates the valve bonnet, through which the stem in the previous problem turns to open and close the valve. There is a wide choice in the selection of the views which may be used to show the piece to best advantage. The bonnet may be drawn in at least four ways, and each one of the drawings would be a good working drawing from which any mechanic could work to good advantage. It would be a matter of opinion as to which one is best. The various selections are listed below.

1. Top, front, and side views (no sections).
2. Top, front, and sectional side views.
3. Top, sectional front, and side views.
4. Top, front, and side views, and partial sectional view through the base on the line of the two small tapped holes and the large reamed hole.

In the first method, all threads will be shown in hidden lines. In the second method, the threads will be shown in hidden lines in the front view, and in section in the side view. The drawing will not show the ribs in the side view, as they are cut away in making the section. The third method will show a section through this rib, which must be indicated conventionally as illustrated in Figure 38. This time the square thread will be shown in section in the front view, but not the tapped hole,

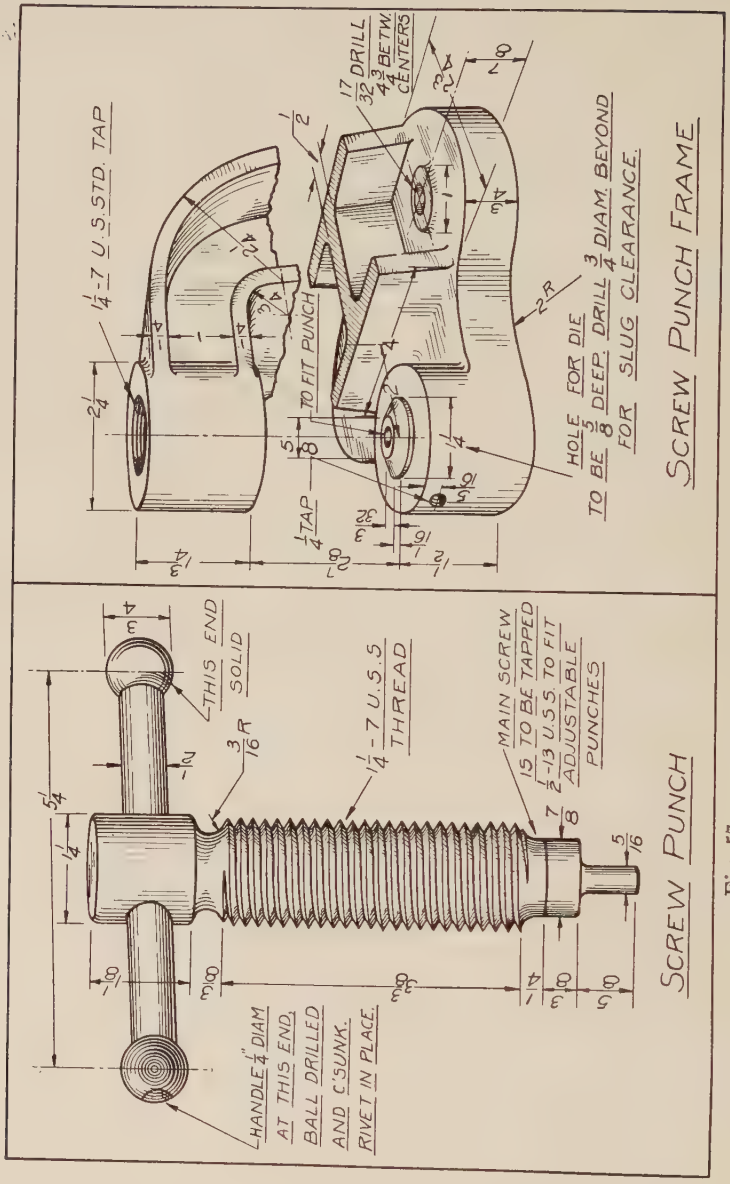

SCREW PUNCH
HANDLE 1/4" DIAM AT THIS END, BALL DRILLED AND C'SUNK, RIVET IN PLACE.
3/16 R
THIS END SOLID
1/4 - 7 U.S.S. THREAD
MAIN SCREW IS TO BE TAPPED 1/2 -13 U.S.S. TO FIT ADJUSTABLE PUNCHES
SCREW PUNCH FRAME
1/4 -7 U.S.STD. TAP
1/4 TAP
TO FIT PUNCH
17/32 DRILL
4 3/4 BETW. CENTERS
HOLE FOR DIE TO BE 5/8 DEEP. DRILL 3/4 DIAM. BEYOND FOR SLUG CLEARANCE.
2 R

Fig. 57 Fig. 58

which does not lie in this plane of section. In the fourth method, the views will be the same as in the first, with a partial view in addition. This view need not be placed in conformity with the rules of projection, but the drawing must include a note stating exactly where the view was taken.

Drawings in which quarter-sectional views are used may also be added to the above methods.

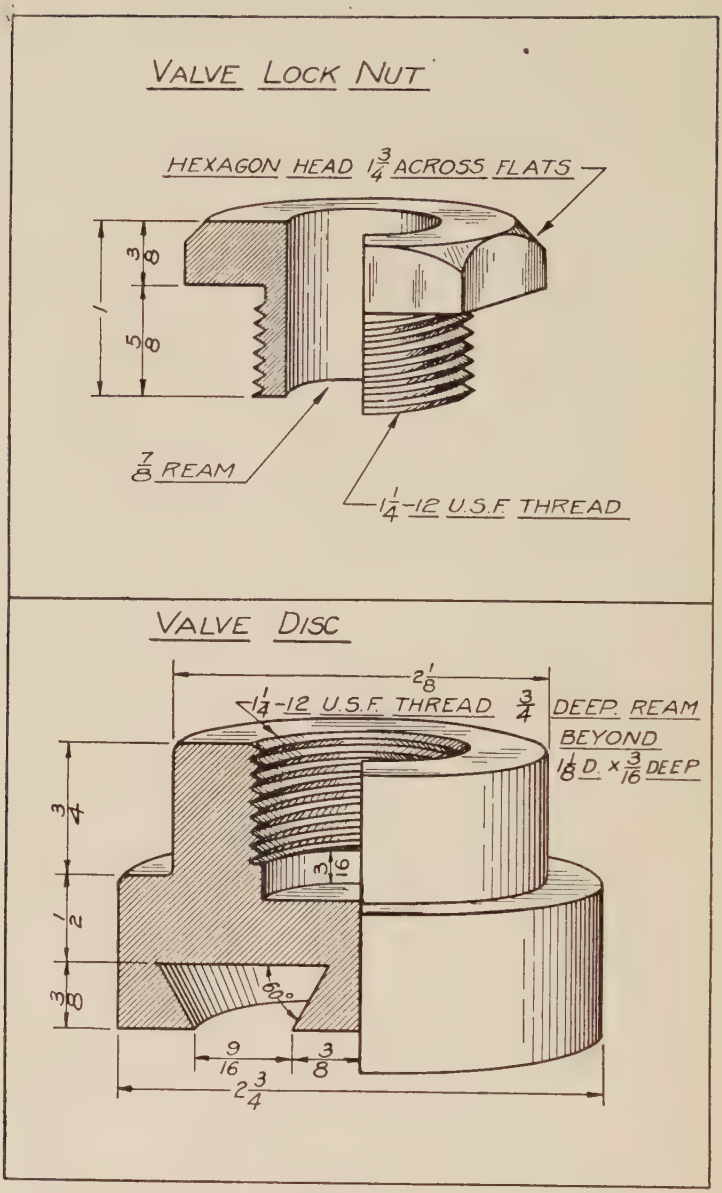
It is suggested at this point that the class be divided into four sections, and each group asked to draw the bonnet in a different way. This will open the way for a discussion of the relative merits of the sectional and the full views. The man in the shop should be considered as he deals with the problem in all its phases, and his point of view should carry great weight.

Screw Punch. The screw punch illustrated in Figure 57 offers an example of a United States Standard thread, which is larger than 1″ in diameter and can be drawn according to the proper convention shown in Figure 50. The handle and the adjustable punch should be drawn independently of the main part of the screw.

The lower end of the front view, in which the tapped hole is to be indicated, may be drawn in two different ways; either a full view showing the tapped hole in hidden lines, or as a broken section.

Screw-Punch Frame. In making a working drawing of the screw-punch frame in Figure 58, it is suggested that a sectional view be made instead of the top view, the section being taken through the frame just above the base. This view will show the shape of the base and the cross section through the H part of the frame. A front and side view will also be required. The removable die shown in the illustration can be detailed separately, as was the handle in the previous problem.

Valve Disc and Lock Nut. The valve disc and the lock nut, illustrated in Figures 59 and 60, are also parts of the valve previously referred to. Note that the threads are not United States Standard, but are marked U. S. F. (U. S. Form). This thread has a finer pitch, or more threads per inch than the U. S. Standard, and while it is not as strong, it will not work loose so easily. Top and front sectional views of each of these pieces should be drawn in making the details.



Figs. 59 and 60

GEOMETRICAL CONSTRUCTION

Hexagon. As one of the pieces in Figure 59 is hexagonal in shape and requires the construction of a hexagon in the top view, an explanation of the construction is necessary. The method given here, however, is not that of the mathematician who uses only a straightedge and a compass, but that of the draftsman, who is equipped with all the necessary instruments and intent on saving as much time as possible in the construction.

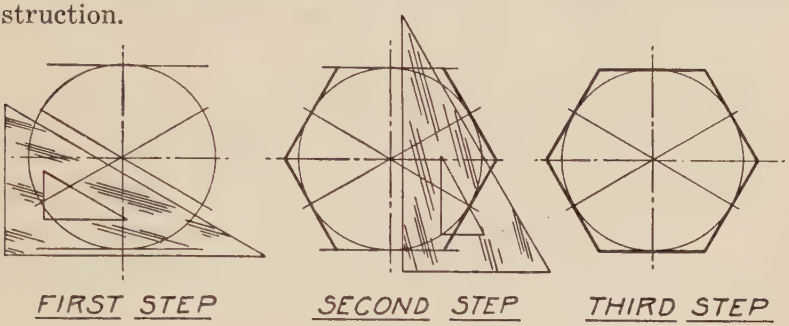


Fig. 61

Assuming the location of the center point of the hexagon, and given the distance across the flats as in Figure 60, draw a circle whose radius is equal to one half of the distance across the flats. Lay the 30°-60° triangle across the center point, and draw the slanting lines shown in Figure 61, first step. Next, swing the triangle around to the position shown in the second step, and draw tangents to the circle through the points at which the first lines intersect it. In finishing the hexagon, it is only necessary to connect these tangents with two others drawn with the T square, through the points where the vertical center line intersects the circle.

The other method of drawing a hexagon is used when the distance across the corners is given instead of the distance across the flats, as in the first case. Figure 62 illustrates the second method. Draw a circle whose radius is equal to one half of the distance across the corners, and draw in the horizontal and vertical center lines. Through the intersections of the horizontal center line and the circle, draw lines at a 60° angle with

the horizontal. End these lines where they intersect the circle a second time, and connect the ends with the T square as in the first method. In order to determine accurately the points where the horizontal lines should intersect the circle lines may be drawn through the center, at an angle of 60° with the horizontal center line. These intersections with the circle determine the points of the hexagon.

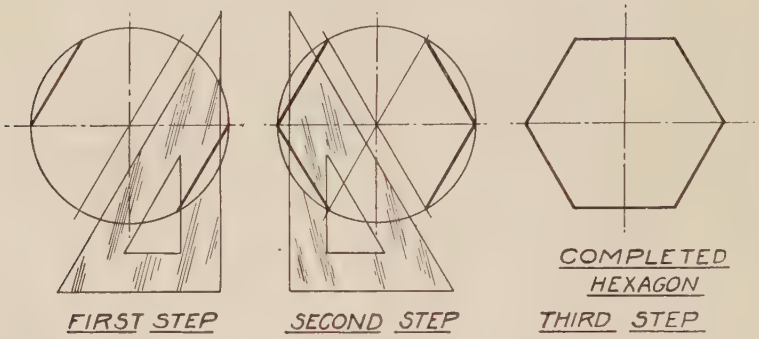


Fig. 62

Bolts and Nuts. Bolts and nuts are in such common use in the construction of machinery that every draftsman should be familiar with their proportions, so that they can be drawn without reference to a handbook. The two used most are the square-head and the hexagon-head bolts with their corresponding nuts. The proportions of these two are shown in Figures 63 and 64.

Hexagon-Head Bolt and Nut. In drawing a bolt and nut, the diameter of the bolt is the basis for determining the dimensions of the head and of the nut. The first step is to find the distance across the flats on the head and nut. This is found by multiplying the diameter of the bolt by one and one half, and adding one eighth of an inch to the result. This can be expressed in a formula in which the distance across the flats equals F and the diameter of the bolt equals D. Then $F = 1\frac{1}{2}D + \frac{1}{8}''$.

The top view of the head can now be drawn by constructing a hexagon as shown in Figure 61. The thickness of the head is equal to one half of the distance across the flats, and the thickness of the nut is equal to the diameter of the bolt itself.

The points of the hexagon are next projected from the other view to show the sides of the head. The corners are chamfered at an angle of 45° and the intersection of this chamfer

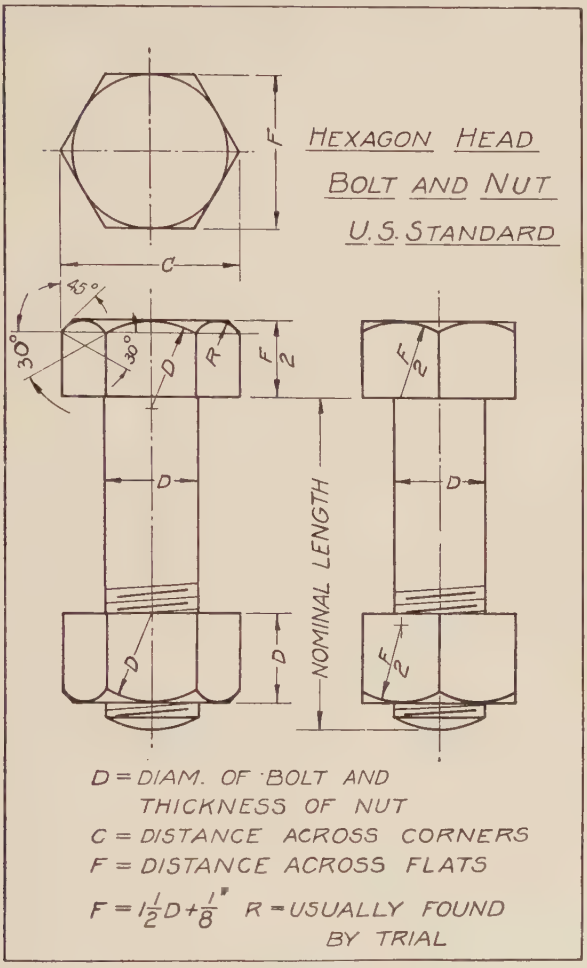


Fig. 63

with the sides is indicated by circular arcs, although they are not strictly true. For the arc across the center section, a radius equal to the diameter of the bolt is used. A horizontal line is drawn through the lower ends of this arc, and lines at an angle of 30° with the horizontal are drawn through the in-

tersections of this line with the corners of the head. The intersections of these lines are used as centers for the arcs indicated by the letter R in the illustration of the bolt and nut in

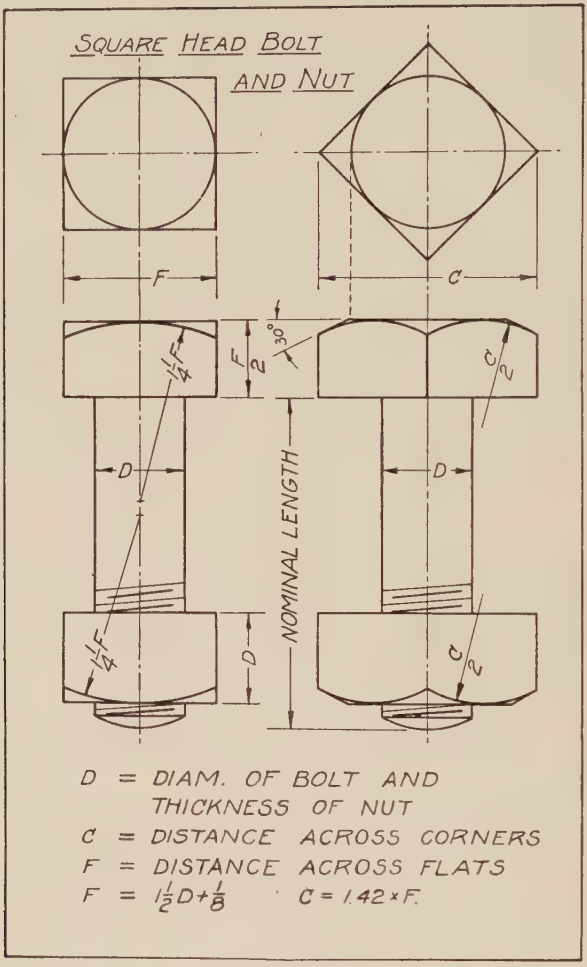


Fig. 64

Figure 63. When the draftsman becomes accustomed to drawing a bolt and nut, he generally locates this center by trial with sufficient accuracy.

In the other view of the bolt and nut, when such views are

required, the chamfer is indicated by arcs whose radius equals the thickness of the head of the bolt. When there is any possibility of interference, the bolt is shown with the distance across corners in both views, thus giving the greatest swing of the head and nut and allowing the interference to be seen.

Square-Head Bolt and Nut. In drawing the square-head bolt and nut, Figure 64, the distance across the flats is found in the same way as in the hexagon-head bolt. The sides of the

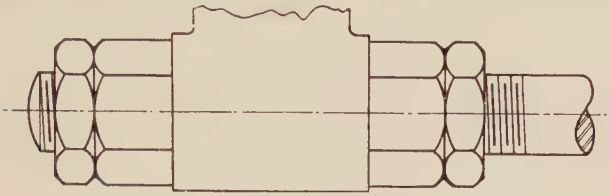


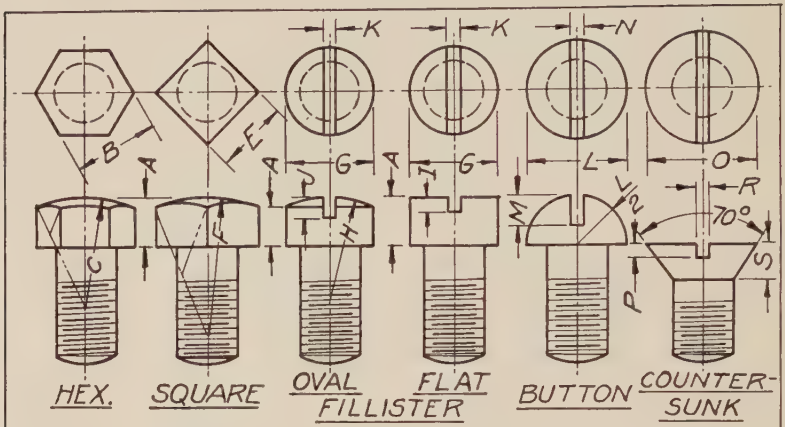
Fig. 65. Lock Nuts

head are made by drawing tangents to the circle, whose diameter equals the distance across the flats. The thickness is again equal to one half of the distance across the flats, while the thickness of the nut is equal to the diameter of the bolt. In the view of the bolt showing only one side of the head, the chamfer is indicated by an arc whose radius is one and one-fourth times the distance across the flats; while in the view which shows the head of the bolt, with the distance across corners, the radius equals one half of this distance. The angle of the chamfer on a square-head bolt and nut is 30°.

Lock Nuts. In order that the vibration of a machine shall not loosen the nut at the end of a bolt, some method is usually provided to lock the nut in place. The common method is to screw another nut on top of the first one, so that they will lock each other against the thread. A nut one half as thick as a standard nut is often used for this purpose, although two nuts of equal thickness are also used. Nuts that are full thickness or three-quarter thickness may also be used. The second nut, or lock nut, is ordinarily chamfered at both ends. Setscrews are usually locked by using a standard nut against the casting into which the screw is set. Figure 65 illustrates the use of the lock nuts as mentioned above.

Other methods of locking are spring washers, pins, and special nuts, such as the castellated nuts used in automobiles.

Cap Screws. Cap screws are used without nuts, passing through a drilled or a reamed hole and threading into a tapped



X = NUMBER OF THREADS PER INCH

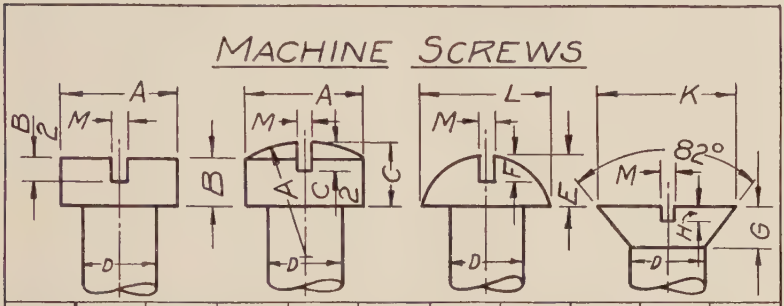
DIA	A	B	C	E	F	G	H	I	J	K	L	M	N	O	P	R	S	X
$\frac{9}{16}$	$\frac{9}{16}$	$\frac{13}{16}$	$1\frac{7}{32}$	$\frac{11}{16}$	$1\frac{3}{8}$	$\frac{13}{16}$	$1\frac{1}{64}$	$\frac{9}{64}$	$\frac{7}{32}$	.114	$\frac{15}{16}$	$\frac{9}{32}$	.114	1	$\frac{7}{64}$	.133	$\frac{5}{16}$	12
$\frac{5}{8}$	$\frac{5}{8}$	$\frac{7}{8}$	$1\frac{5}{16}$	$\frac{3}{4}$	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{32}$	$\frac{5}{32}$	$\frac{15}{64}$	.128	1	$\frac{5}{16}$	.133	$1\frac{1}{8}$	$\frac{1}{8}$	.133	$\frac{23}{64}$	11
$\frac{3}{4}$	$\frac{3}{4}$	1	$1\frac{1}{2}$	$\frac{7}{8}$	$1\frac{3}{4}$	1	$1\frac{1}{4}$	$\frac{3}{16}$	$\frac{9}{32}$	.133	$1\frac{1}{4}$	$\frac{3}{8}$	.133	$1\frac{3}{8}$	$\frac{5}{32}$	.133	$\frac{7}{16}$	10
$\frac{7}{8}$	$\frac{7}{8}$	$1\frac{1}{8}$	$1\frac{11}{16}$	$1\frac{1}{8}$	$2\frac{1}{4}$	$1\frac{1}{8}$	$1\frac{13}{32}$	$\frac{7}{32}$	$\frac{21}{64}$	.133								9
1	1	$1\frac{1}{4}$	$1\frac{7}{8}$	$1\frac{1}{4}$	$2\frac{1}{2}$	$1\frac{1}{4}$	$1\frac{9}{16}$	$\frac{1}{4}$	$\frac{3}{8}$	.165								8
$1\frac{1}{8}$	$1\frac{1}{8}$	$1\frac{3}{8}$	$2\frac{1}{16}$	$1\frac{3}{8}$	$2\frac{3}{4}$													7
$1\frac{1}{4}$	$1\frac{1}{4}$	$1\frac{1}{2}$	$2\frac{1}{4}$	$1\frac{1}{2}$	3													7
$1\frac{3}{8}$	$1\frac{3}{8}$	$1\frac{5}{8}$	$2\frac{7}{16}$	$1\frac{5}{8}$	$3\frac{1}{4}$													6

Fig. 66

hole in the next piece. Cap screws are made in six standard forms: hexagon, square, oval fillister, flat fillister, button, and countersunk heads. The table given in Figure 66 has for its smallest screws those of $\frac{9}{16}$" in diameter and the largest $1\frac{3}{8}$", although all types of heads are not available in the larger diameters, as shown by the blank spaces in the table. All screws

are measured for length from the underside of the head, with the exception of the countersunk-head screw, in which the thickness of the head is included in the length.

Machine Screws. Machine screws are used mostly on small machine parts, or where no great strength is required. The



D	A	B	C	E	F	G	H	K	L	M
.060	.089	.038	.050	.042	.031	.029	.010	.112	.106	.025
.073	.111	.046	.061	.051	.035	.037	.012	.138	.130	.028
.086	.132	.055	.072	.060	.040	.045	.015	.164	.154	.030
.099	.153	.063	.084	.069	.044	.052	.017	.190	.178	.032
.112	.175	.072	.095	.078	.049	.060	.020	.216	.202	.034
.125	.196	.081	.107	.087	.053	.067	.022	.242	.226	.037
.138	.217	.089	.118	.096	.058	.075	.025	.262	.250	.039
.151	.239	.098	.130	.105	.062	.082	.027	.294	.274	.041
.164	.260	.106	.141	.114	.067	.090	.030	.320	.298	.043
.177	.281	.115	.152	.123	.071	.097	.032	.346	.322	.046
.190	.303	.123	.164	.133	.076	.105	.035	.372	.346	.048
.216	.345	.141	.187	.151	.085	.120	.040	.424	.394	.052
.242	.388	.158	.210	.169	.094	.135	.045	.472	.443	.057
.268	.431	.175	.233	.187	.103	.150	.050	.528	.491	.061
.294	.473	.192	.255	.205	.112	.164	.055	.580	.539	.066
.320	.516	.209	.278	.224	.122	.179	.060	.632	.587	.070
.346	.558	.226	.301	.242	.131	.194	.065	.682	.635	.075
.372	.601	.244	.324	.260	.140	.209	.070	.732	.683	.079
.398	.644	.261	.347	.278	.149	.224	.075	.788	.731	.084
.424	.686	.278	.370	.296	.158	.239	.080	.840	.779	.088
.450	.727	.295	.402	.315	.167	.254	.085	.892	.827	.093

Fig. 67

largest of the machine screws is only .450″ in diameter. Formerly, the sizes of machine screws were noted by a number and the number of threads per inch on the screw; but this has been changed, so that now the screws are noted by their diameters in thousandths of an inch. The diameters of machine screws and the corresponding number of threads per inch are given in the following table.

TABLE OF MACHINE SCREWS

Diam.	No. Thds.	Diam.	No. Thds.	Diam.	No. Thds.
.060	80	.151	36	.294	20
.073	72	.164	36	.320	20
.086	64	.177	32	.346	18
.099	56	.190	30	.372	16
.112	48	.216	28	.398	16
.125	44	.242	24	.424	14
.138	40	.268	22	.450	14

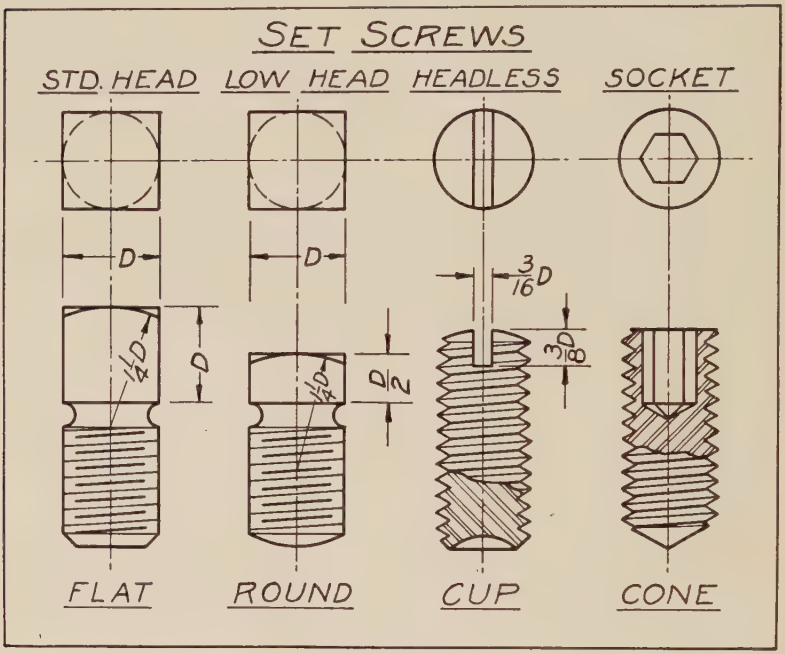


Fig. 68

Figure 67 shows the shapes and proportions of the four types of heads used on machine screws.

Setscrews. Setscrews are used to hold machine parts in proper adjustment. They are manufactured with four different kinds of heads and almost any desired shape of point. The four kinds of heads in use are the standard square head,

the low square head, the headless screw with a screwdriver slot in the end, and the headless screw with a socket in the end for screwdriver and socket wrenches respectively. The last two types are used on moving parts as a safety-first measure, because the heads of the other two types are too dangerous when revolving where they may possibly catch a person's clothing. The points most commonly used are the flat, round, cup, and cone points. Illustrations of the above heads and points are given in Figure 68.

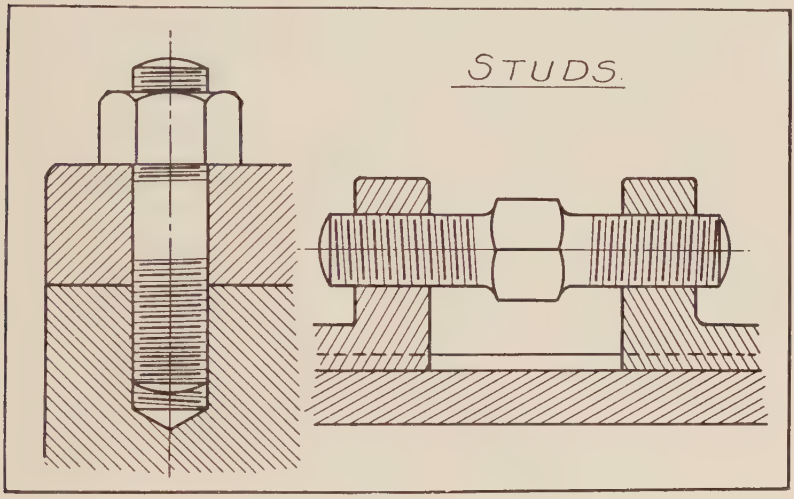


Fig. 69

Studs. It is necessary quite often to remove some part of a machine frequently. This makes cap screws undesirable, as the threads in the machine part wear out and may eventually strip, sometimes requiring the replacement of any expensive piece of machinery. To overcome this difficulty, studs are used. A "stud" is a screw threaded at both ends, so that one end may be permanently screwed into the tapped hole in the machine, while the other end projects through the second piece to receive a nut. When, in the course of time, the thread on the stud wears out, it is not expensive to replace.

This kind of stud is threaded in the same direction on both ends unless it is otherwise specified. Another kind of stud is

the one used to hold machine parts in proper adjustment. This kind is threaded in opposite directions, so that, by turning the stud in one direction, the parts are brought closer together, while turning it in the other direction will separate the machine parts. Between the ends there must be a section, either square or hexagonal, on which a wrench may get a grip. Both studs are illustrated in Figure 69.

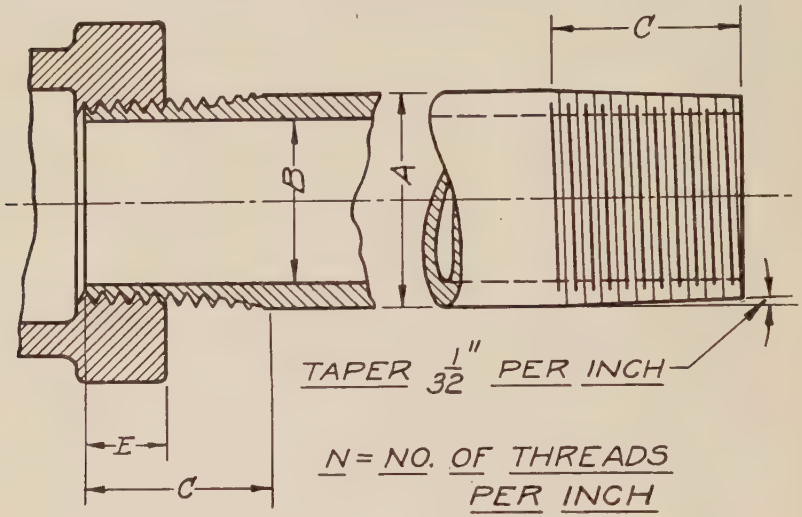


Fig. 70. Pipe Threads

Pipe and Pipe Threads. Due to the extensive use of pipe of various kinds in machine construction and operation, a knowledge of the conventional methods of representation on drawings is essential.

Pipe Standards. Wrought iron and steel pipe is made in three weights: standard, extra heavy, and double extra heavy. Pipe is known by its nominal diameter, which is somewhere near, but not exactly, the inside diameter of the standard pipe. Extra heavy and double extra heavy pipe is obtained by reducing the inside diameter of the standard pipe, leaving the outside diameter unchanged, so that the same threading tools can be used in making connections. Thus, for any nominal size, the outside diameter remains the same for all of the three weights.

The smaller sizes of pipe have threaded connections, while the larger pipes are flanged and bolted together.

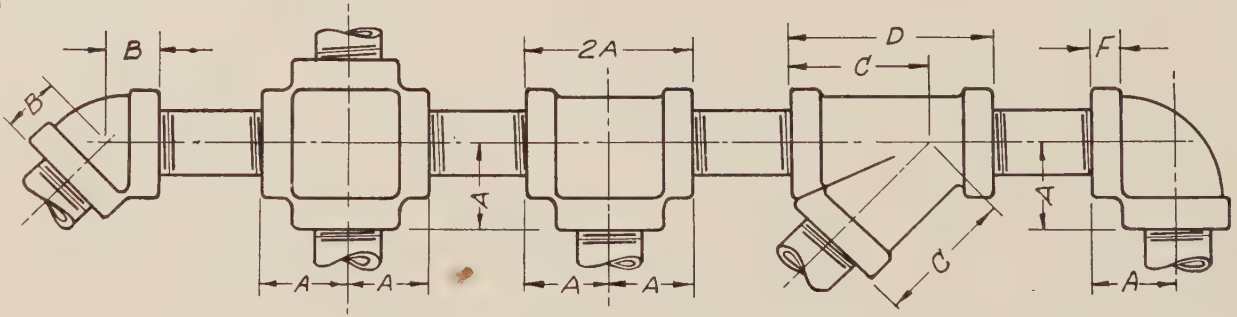
Pipe Threads. The system of pipe threads used in the United States is the Briggs Standard, in which the thread tapers $\frac{1}{32}$ of an inch per inch of length. The conventional method of showing pipe threads is illustrated in Figure 70. The following table gives the relative dimensions for all sizes of pipe:

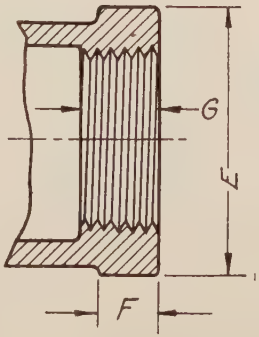
D = nominal diameter.
A = actual inside diameter.
B = actual outside diameter.
C = total length of threads.
E = length of perfect threads and the distance which a pipe screws into a connection.
N = the number of threads per inch.

BRIGGS PIPE THREAD

Diameter of Pipe			No. of Threads Per Inch
Nominal Inside	Actual Inside	Actual Outside	
$\frac{1}{8}$	.270	.405	27
$\frac{1}{4}$	.364	.540	18
$\frac{3}{8}$	.494	.675	18
$\frac{1}{2}$	.623	.840	14
$\frac{3}{4}$	.824	1.050	14
1	1.048	1.315	$11\frac{1}{2}$
$1\frac{1}{4}$	1.380	1.660	$11\frac{1}{2}$
$1\frac{1}{2}$	1.610	1.900	$11\frac{1}{2}$
2	2.067	2.375	$11\frac{1}{2}$
$2\frac{1}{2}$	2.468	2.875	8
3	3.067	3.500	8
$3\frac{1}{2}$	3.548	4.000	8
4	4.026	4.500	8
$4\frac{1}{2}$	4.508	5.000	8
5	5.045	5.563	8
6	6.065	6.625	8
7	7.023	7.625	8
8	7.982	8.625	8
9	8.937	9.625	8
10	10.019	10.750	8

Pipe Fittings. The pipe fittings, or connections, most commonly used are the 45° and 90° elbow, and the tee, cross, and wye. Figure 71 illustrates the generally accepted method of





PIPE SIZE NOM.	PIPE SIZE ACTUAL	A	B	C	D	E	F	G
1/4	.540	3/4	7/16			1	1/4	3/8
3/8	.675	7/8	9/16	1 7/16	2 1/16	1 1/8	5/16	7/16
1/2	.840	1 1/16	11/16	1 7/8	2 9/16	1 7/16	3/8	1/2
3/4	1.050	1 5/16	13/16	2 1/16	2 3/4	1 3/4	7/16	9/16
1	1.315	1 1/2	15/16	2 1/2	3 1/4	2 1/16	1/2	5/8
1 1/4	1.660	1 13/16	1 1/16	3	3 3/4	2 1/2	9/16	11/16
1 1/2	1.900	2	1 3/16	3 1/4	4 3/4	2 3/4	5/8	13/16
2	2.375	2 3/8	1 3/8	4	5 1/2	3 3/8	11/16	7/8
2 1/2	2.875	2 7/8	1 5/8	5	6 13/16	4 1/8	13/16	1
3	3.500	3 5/16	1 7/8	5 5/8	7 5/8	4 3/4	15/16	1

Fig. 71

indicating such fittings in a drawing. The table gives the Walworth Company standard of the dimensions for fittings from $\frac{1}{4}''$ to 3″ nominal diameter.

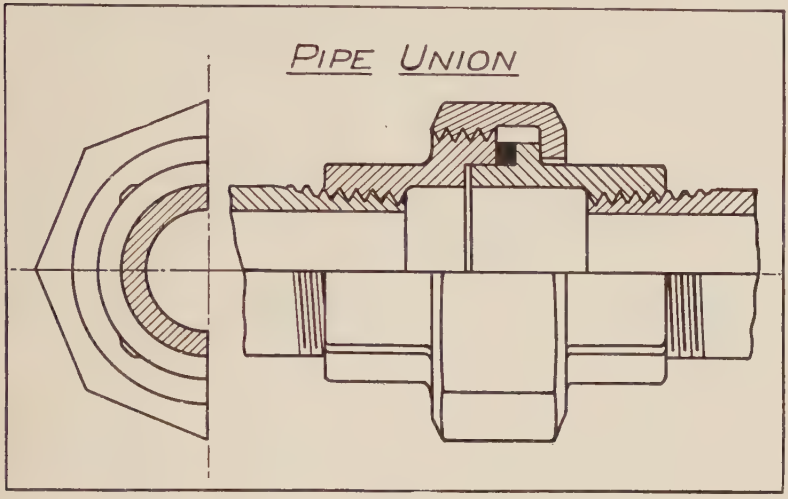


Fig. 72

Unions. Unions are used to connect parts of a pipe line which would otherwise be difficult to assemble. A union consists of four parts: two of these are screwed to the pipes to be connected; the third, a rubber or leather gasket is placed between them; and the fourth, a nut, is used to draw all of them together to prevent leakage. A quarter-section view of a union is shown in Figure 72. There are several different makes of unions on the market, but practically all of them are constructed on the same principle. The thread in the nut, which is used to draw the parts together, is not a pipe thread, that is, this thread is not tapered, for then it would not draw the union tight.

CHAPTER V

GEARING

The subject of gearing is of great importance to both designers and draftsmen. The draftsman does not, as a rule, calculate the strength of gear teeth or the efficiency of operation. However, he must be able to calculate the proper proportions of teeth and to dimension them, so that a machinist working from his drawings will meet no difficulty in their interpretation.

Types of Gears. In machine construction, many types of gears are in use, but only three are of sufficient importance and at the same time not too difficult to study in this course. The type of gears required for a certain place on a machine depends on the following factors:

1. Relative positions of the shafts on which the gears are to run.
2. Relative speeds at which the shafts are to revolve.

The following types of gears will be taken up for study:

Spur Gears. Spur gears are used when the shafts are parallel.

Bevel Gears. Bevel gears are used when the shafts are in the same plane, but intersect instead of being parallel.

Worm Gears. This type of gears is used when the shafts do not lie parallel and do not intersect.

Spur Gears. Spur gears are wheels with rims on which the teeth engage and form a rolling and sliding contact with each other. The shape of the teeth must be calculated very carefully, so that there will be no lost motion or the shafts will not revolve uniformly. The general proportions of teeth which run together are the same, but there is a difference in the shape of the sides of the teeth which varies with the diameter of the gear.

Speed Ratios. The first consideration in drawing a set of spur gears is the question of the relative speeds at which the gears are to run. It is obvious that the smaller gear will make the greater number of revolutions. The speeds are calculated on the pitch diameters, or pitch circles. The pitch circles in

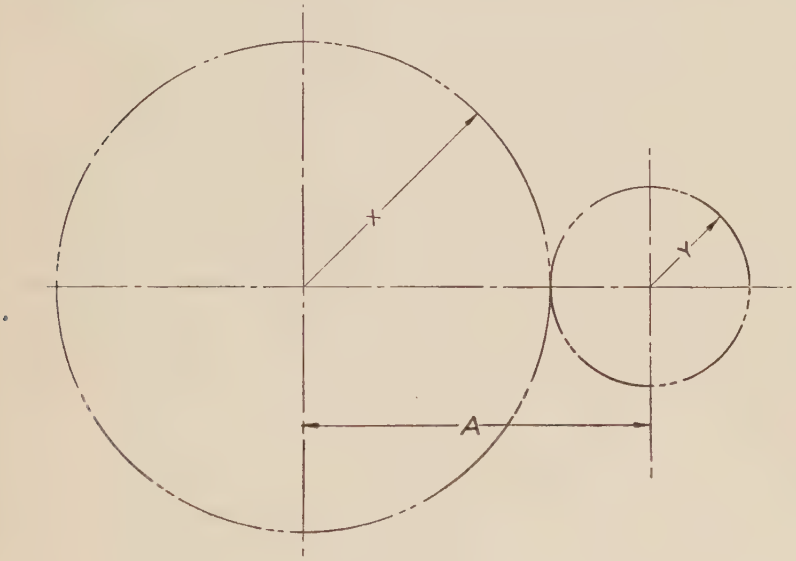


Fig. 73

two mating gears are always tangent to each other. They are considered in much the same manner as two wheels running rim to rim.

Factors Affecting Gear Calculation. Three main factors affect the calculation of gears and gear teeth.

1. The distance between the centers of the two shafts.
2. The relative speeds of the two gears.
3. The size (diametral pitch) of the teeth.

Due to some of the characteristics of certain machines, any of the above factors may be fixed quantities, resulting in a slight change in the others, so that the teeth in the gears may be cut without going to the expense of making special cutters. These conditions can be classified into the three next items which explain what is to be done in each case.

Fixed Distance Between Shafts. If the distance between the centers of the shafts is such that it cannot be changed, it will be necessary to alter the speed ratio or the diametral pitch which was originally selected. In some cases, it may be necessary to change both.

Fixed Speed Ratio. When the machine requirements are such that the shafts must revolve at a certain speed ratio, then the distance between centers, or the diametral pitch, or both may have to be altered.

Fixed Diametral Pitch. In the case of broken gears, when a drawing must be made for replacement purposes, the other gears are not changed, and the diametral pitch of the broken gear and the number of teeth are used to obtain all the other dimensions.

Formulas and Examples. The formula for obtaining the pitch diameters of two gears from the speed ratio and the distance between centers is derived as follows:

Let A equal the distance between centers.
Let c equal the speed of one gear (pinion),
And let d equal the speed of the other gear.

Then $\frac{c}{d}$ equals the speed ratio.

Let x equal the pitch radius of the large gear,
And let y equal the pitch radius of the pinion.
Then $x + y = A$ I
and $x : y = c : d$ II
whence $dx = cy$ III
Multiplying equation I by c
$cx + cy = cA$ IV
Substituting dx for cy in equation IV
$cx + dx = cA$ V
Factoring the left-hand member
$(c + d)\ x = cA$ VI
Dividing both sides by $c + d$

$$x = \frac{cA}{c + d}$$

By a similar method, the value of y is found to be

$$y = \frac{dA}{c + d}$$

Figure 73 should be referred to in these calculations.

Example:

In a pair of spur gears, the distance between centers is 10″ and the ratio of their speeds is as 5 to 2. Find the pitch diameters of the two gears.

Let x = the pitch radius of the gear.
Let y = the pitch radius of the pinion.

$$x = \frac{5 \cdot 10}{5 + 2} = \frac{50}{7} = 7.1428$$

$$y = \frac{2 \cdot 10}{5 + 2} = \frac{20}{7} = 2.8571$$

$2x$ or the pitch diameter of the gear $= 14.2856$
$2y$ or the pitch diameter of the pinion $= 5.7142$

These diameters can be used only when the selected diametral pitch, if multiplied by the pitch diameter, will result in a whole number, which then represents the number of teeth in the gear. Thus, the above diameters would be good when the diametral pitch is $3\frac{1}{2}$, 7, or 14, but any other numbers would result in a fractional number of teeth, which would be an impossibility in practice.

Example:

Find the pitch diameters of two gears having given the following information:

Speed ratio ..... 4 : 7 (fixed)
Diametral pitch ..... $3\frac{1}{2}$ (fixed)
Distance between centers ..... $4\frac{1}{2}$″ (approx.)

Using the same method as was used in the previous example, it is found that the gears cannot be cut under these exact conditions. Therefore, the nearest distance to $4\frac{1}{2}$″ which is practical will have to be found.

Let A = distance between centers.
b = sum of the number of teeth in both gears.
p = diametral pitch.

The distance between centers is equal to the sum of the teeth in both gears, divided by twice the diametral pitch. In the form of an equation this would be

$$A = \frac{b}{2p} \text{ whence } b = 2Ap$$

When $A = 4\frac{1}{2}$, $p = 3\frac{1}{2}$, $b = 2 \cdot 4\frac{1}{2} \cdot 3\frac{1}{2} = 31\frac{1}{2}$.

The nearest whole number to $31\frac{1}{2}$, exactly divisible by the sum of the terms of the speed ratio $(4 + 7)$, is 33, which will be the sum of the teeth in both gears. This number is now substituted for $31\frac{1}{2}$ in the formula, which becomes

$$A = \frac{33}{2 \cdot 3\frac{1}{2}} = \frac{33}{7} = 4.7142$$

This is the center distance of the two gears to be designed.

The center distance is divided by the sum of the terms of the speed ratio, and the result multiplied by twice each of these terms to obtain the pitch diameters of the two gears as shown in the following:

$$\frac{A}{c + d} = \frac{4.7142}{11} = .4285$$

$.4285 \cdot 2 \cdot 4 = 3.428$ = pitch diameter of pinion
$.4285 \cdot 2 \cdot 7 = 5.999$ or 6.000 = pitch diam. of gear.

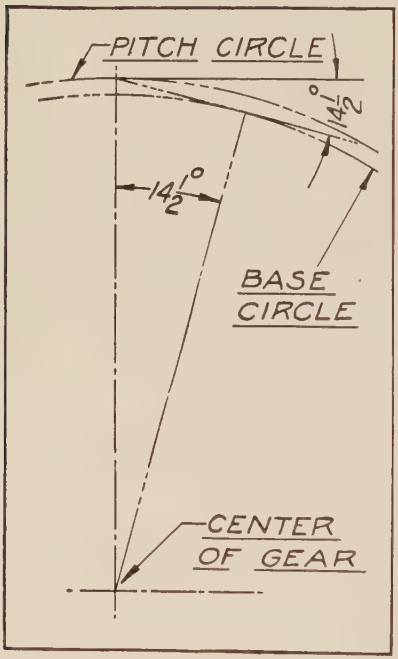


Fig. 74

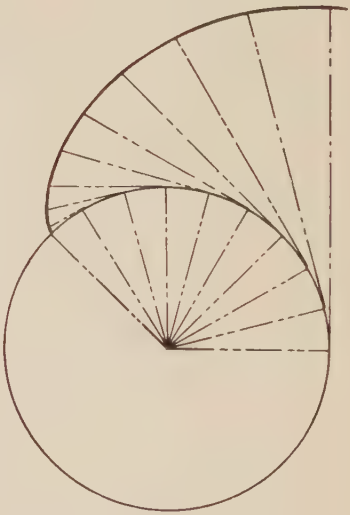


Fig. 75. The Involute Curve

Tooth Forms and Proportions. The tooth form which has come into general use is the involute tooth with a pressure angle of $14\frac{1}{2}°$. This tooth was adopted many years ago by the Brown and Sharpe Company. The profile, or shape, of the tooth is generated from a base circle, found as follows:

A line is drawn through the center of the gear at an angle of $14\frac{1}{2}°$ with the vertical center line. Another line is drawn through the intersection of the vertical center line with the pitch circle, at an angle of $14\frac{1}{2}°$ with the horizontal center line. The base circle is drawn with its center at the center of the gear through the point at which the above lines intersect.

The involute is generated from this circle in a manner similar to a string being unwound from a cylinder. The point at the end of the string generates an involute curve.

The method of finding the base circle is illustrated in Figure 74, while the method of generating an involute from a base circle is shown in Figure 75. The part outside the base circle on the profile of a tooth is called the "face," while the part of the tooth inside the base circle is called the "flank." The flank is usually drawn as a radial line.

In Figure 76, most of the tooth proportions are shown and the names of the various parts are indicated.

The distance from the pitch circle to the outside circle is called the "addendum."

The distance from the pitch circle to the bottom of the tooth is called the "dedendum," and consists of the addendum plus the clearance.

The thickness of the tooth is measured along the pitch circle, between the points where the tooth profile crosses the pitch circle.

Notation. For use in the calculation of gears, the following notation should be used:

A = distance between centers of shafts.
p = diametral pitch.
D' = pitch diameter of the gear.
d' = pitch diameter of the pinion.
D = outside diameter of the gear.
d = outside diameter of the pinion.
N = number of teeth in the gear.

n = number of teeth in the pinion.
s = addendum.
$s + f$ = dedendum.
W = working depth.
W' = whole depth.
t = the thickness of tooth on the pitch circle.

Formulas. The following formulas will be used in calculating dimensions of gear teeth:

$$p = \frac{N}{D'} = \frac{n}{d'} = \frac{N+2}{D} = \frac{n+2}{d}$$

$$s = \frac{1}{p} \qquad D = D' + 2s = D' + \frac{2}{p} = \frac{N+2}{p}$$

$$N = pD' = pD - 2 \qquad d = d' + 2s = d' + \frac{2}{p} = \frac{n+2}{p}$$

$$D' = \frac{DN}{N+2} = \frac{N}{p} \qquad d' = \frac{dn}{n+2} = \frac{n}{p}$$

$$t = \frac{1.5708}{p} \qquad f = \frac{t}{10} = \frac{.15708}{p} \qquad W = 2s \qquad W' = 2s + f.$$

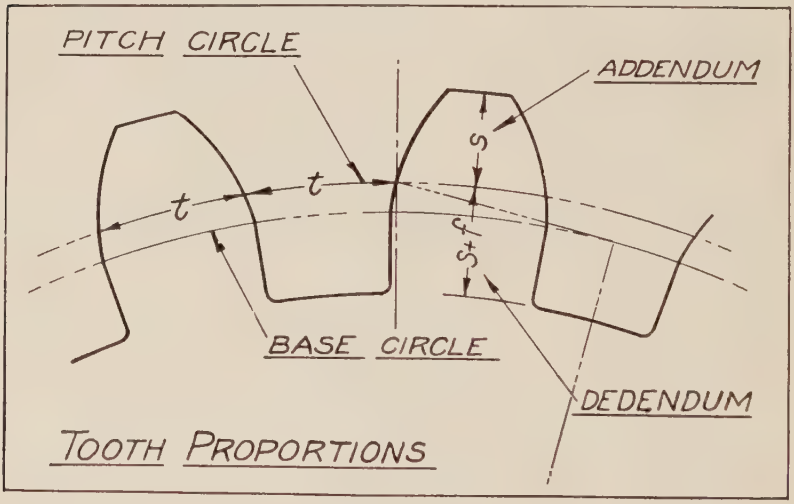


Fig. 76

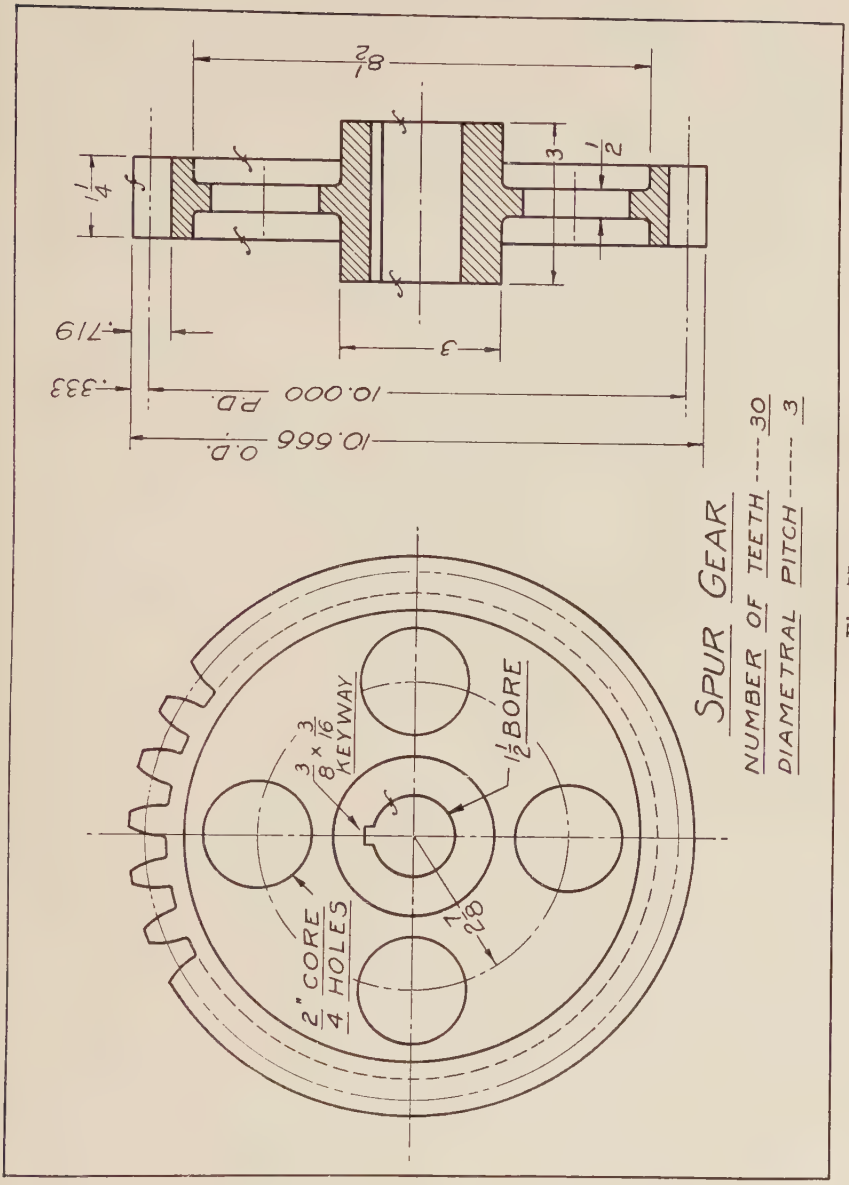

SPUR GEAR
NUMBER OF TEETH ---- 30
DIAMETRAL PITCH ---- 3
10.666 O.D.
10.000 P.D.
.333
.719
1/4
3
1/2
3
8 1/2
1/2 BORE
3/8 x 3/16 KEYWAY
2" CORE 4 HOLES
28

Fig. 77

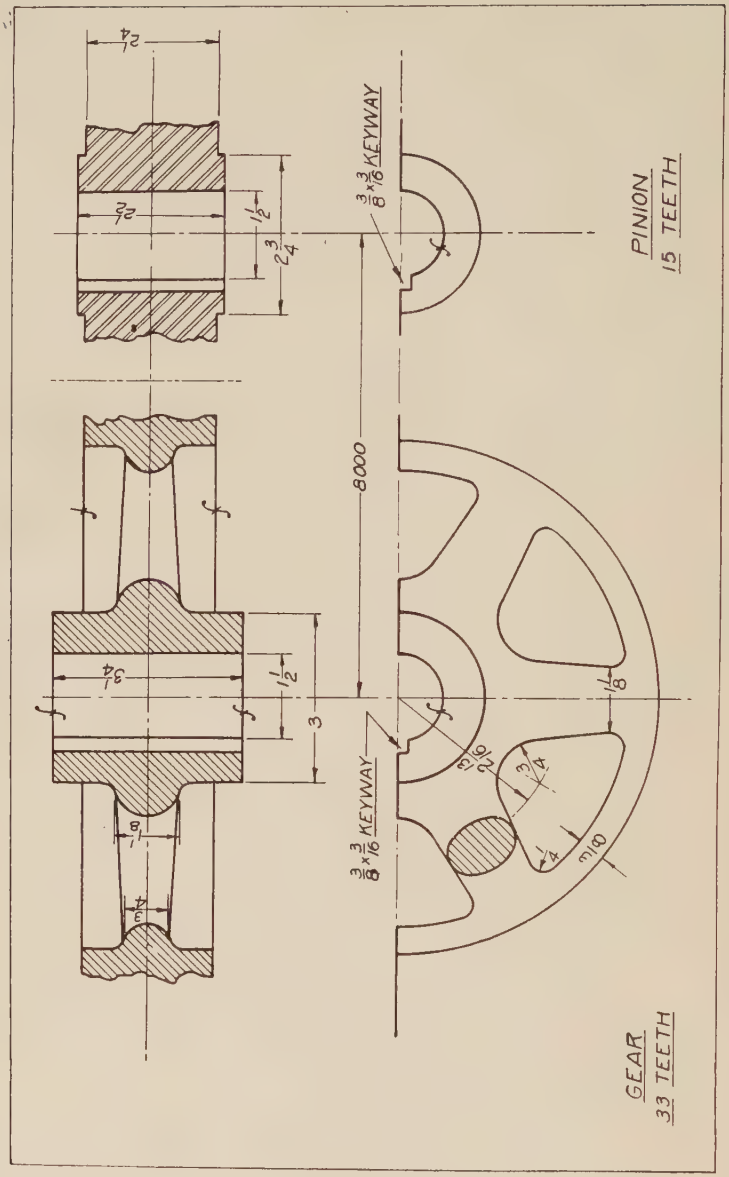

PINION
15 TEETH
GEAR
33 TEETH
8000
3/8 × 3/16 KEYWAY
3/8 × 3/16 KEYWAY

Fig. 78

Gear Drawings. Due to the accuracy required in cutting, the fractional dimensions generally used in mechanical drawing are not sufficiently close. Consequently, all the dimensions which apply to the teeth and the diameters used in calculating or in cutting the teeth are given on the drawing in decimals, usually to the nearest thousandth of an inch. Figure 77 is a drawing of a spur gear. It is calculated according to the above formulas and properly dimensioned, showing all the dimensions relating to the teeth in decimals and other dimensions in fractions.

Drawing Problems in Spur Gears. Draw a spur gear having 21 teeth and a pitch diameter of 7.000″. The face of the teeth should be $1\frac{1}{4}$″ wide, the inside rim diameter $5\frac{1}{4}$″, the web $\frac{1}{2}$″ thick, four cored holes 1″ in diameter in the web, diameter of hub $2\frac{1}{2}$″, length of hub $2\frac{3}{4}$″, bore of hub $1\frac{1}{4}$″, and a keyway $\frac{5}{16}$″ wide by $\frac{5}{32}$″ deep. In this drawing show all the teeth. Use a B-size sheet and make two views, one a sectional view. Be careful not to section the teeth.

Draw a pair of spur gears, using the following information:

Distance between centers	8.000″
Speed ratio	11 to 5
Diametral pitch	3
Width of face	$2\frac{1}{4}$″

The hubs of these gears are illustrated in Figure 78. This part of the drawing should be redrawn on a C-size sheet, and the unfinished part completed, together with the calculations for the teeth. In finishing the drawing, only a few teeth should be shown on each gear at the point where they mesh.

Bevel Gears. Bevel gears have the form of cones instead of cylinders, and the center lines of the shafts intersect. In this book, only bevel gears on shafts which intersect at right angles are taken up. The chapter on the solution of triangles will require some study in connection with these gears, as several triangles must be solved in order to determine the dimensions of some of the parts of the bevel gears.

Notation. The following notation should be used in the calculation of bevel gears:

D' = pitch diameter.
D = outside diameter.
N_1 = number of teeth in the gear.
N_2 = number of teeth in the pinion.
p = diametral pitch.
t = thickness of tooth on the pitch line at the large end.
s = addendum.
f = clearance.
$s + f$ = dedendum.
E = center angle.
F = face angle.
C = cutting angle.
J = addendum angle.
K = dedendum angle.
V = diameter increment.
Y = backing.
a = distance from a point on the pitch circle to the apex.
b = width of face of teeth.
H = distance from pitch circle to center of opposite shaft.
P = distance from point of tooth to center of opposite shaft.

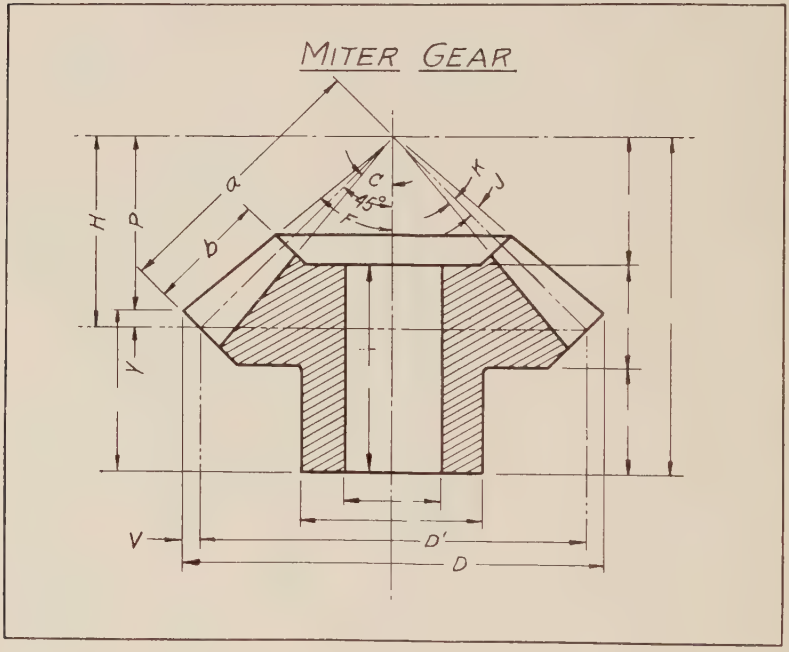


Fig. 79

Miter Gears. Miter gears are bevel gears having an equal number of teeth designed to run together. In making a drawing of a set of miter gears, it is unnecessary to draw both gears unless there is a difference in the design of the hubs, because all dimensions pertaining to the teeth will be exactly alike for both gears. Usually only one view is drawn of any bevel gear, whether it is a miter gear or another. A bevel gear is best drawn in section so as to provide a better opportunity for dimensioning.

Figure 79 illustrates a miter gear drawn in one sectional view. All dimensions pertaining to the teeth are given in the letters used in the notation, and all other dimensions are left blank. Great care should be taken in dimensioning bevel gears, so that the machinist will have no trouble in turning up the blank. A machinist should not be required to make calculations which can be given on the drawing.

Unequal Bevel Gears. In the notation for spur gears, no attention was paid to differentiating between the notation for the gear and for the pinion. This is taken care of by using the subscript (1) for the gear and the subscript (2) for the pinion. The formulas for obtaining the dimensions for both miter and other bevel gears are contained in the following table:

Figure 80*a* illustrates the method of drawing bevel gears in pairs. This drawing and the table on page 90 should be referred to when drawing the bevel gears in the following problems.

Figures 80*b* and 80*c* illustrate the steps in laying out a pair of bevel gears.

First step. Lay out the shaft center lines, pitch lines, and pitch cones.

Second step. Lay out the width of the face of the teeth in both gear and pinion, by drawing lines perpendicular to the pitch cones lines.

Third step. Step off addendum and dedendum, and draw the teeth by lines through the intersection of the shaft center lines.

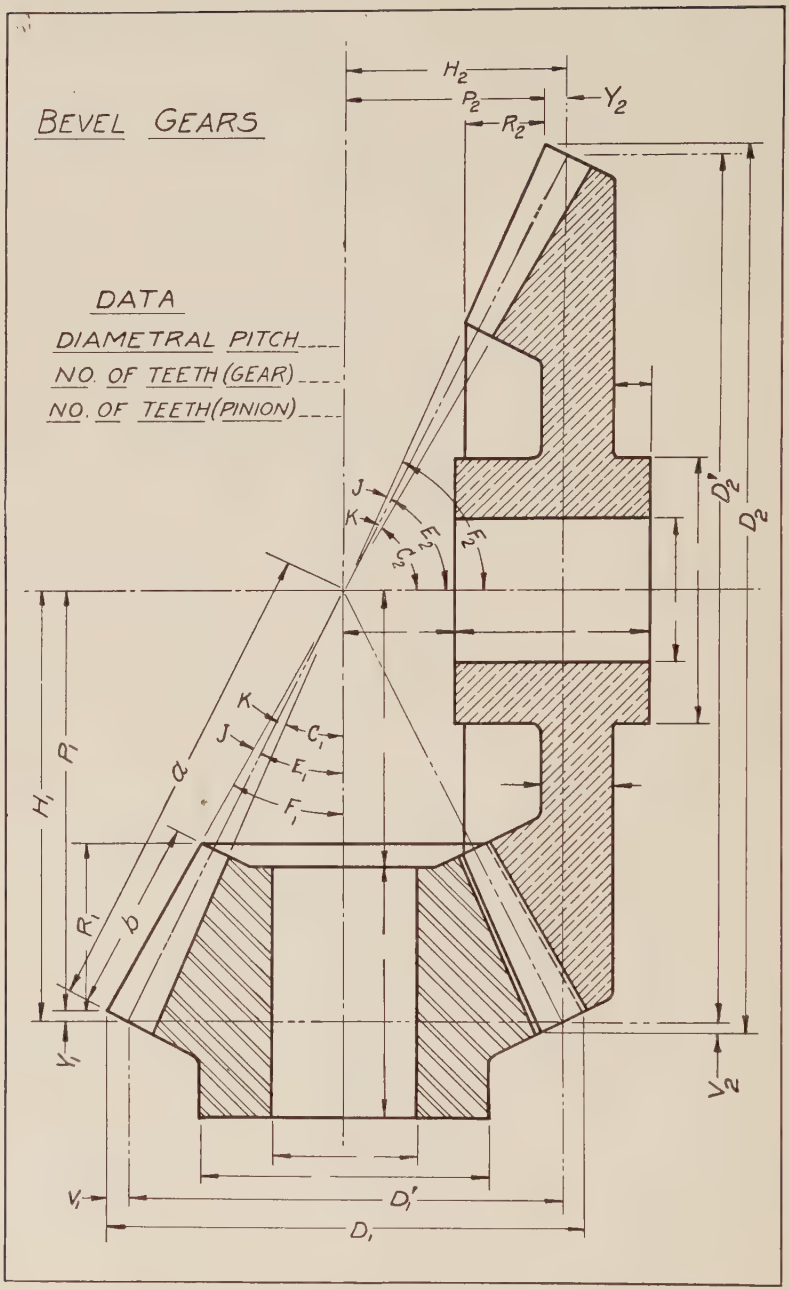

BEVEL GEARS
DATA
DIAMETRAL PITCH----
NO. OF TEETH (GEAR)----
NO. OF TEETH (PINION)----
H_2
P_2
R_2
Y_2
D_2'
D_2
J
K
E_2
C_2
F_2
K
J
C_1
E_1
F_1
H_1
P_1
a
b
R_1
Y_1
V_2
V_1
D_1'
D_1

Fig. 80a

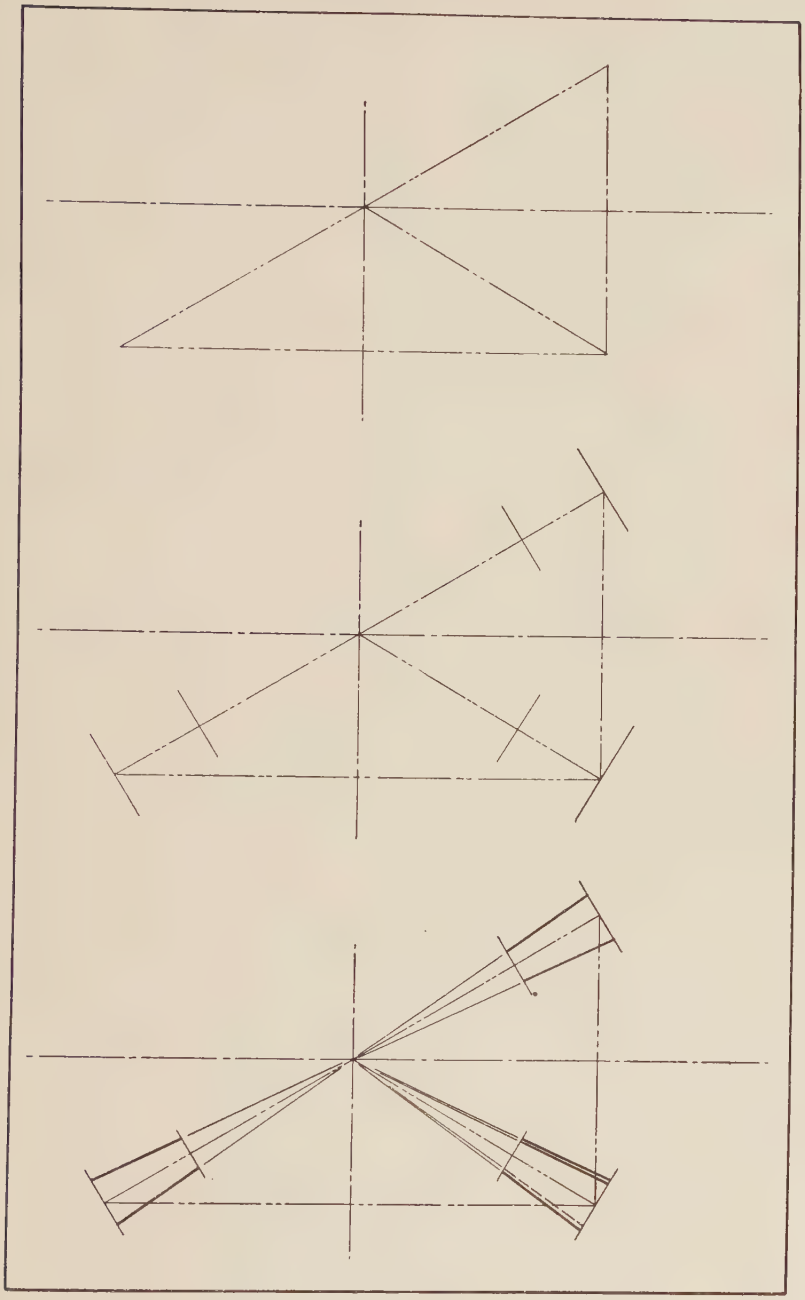


Fig. 80b

Fourth step. Draw the hubs of both gear and pinion.
Fifth step. Cross section.
Sixth step. Dimension.

TABLE FOR FINDING BEVEL-GEAR DIMENSIONS

Dim.	Miter	Dim.	Gear	Dim.	Pinion
E	$45°$	E_1	$\tan E_1 = \frac{N_1}{N_2}$	E_2	$90° - E_1$
J	$\tan J = \frac{s}{a}$	J	$\tan J = \frac{s}{a}$	J	$\tan J = \frac{s}{a}$
K	$\tan K = \frac{s+f}{a}$	K	$\tan K = \frac{s+f}{a}$	K	$\tan K = \frac{s+f}{a}$
F	$45° + J$	F_1	$E_2 + J$	F_2	$E_2 + J$
C	$45° - K$	C_1	$E_2 - K$	C_2	$E_2 - K$
a	$D' \times .7071$	a	$\frac{D_2}{2 \sin E_2}$	a	$\frac{D_1}{2 \sin E_1}$
V	$s \times .7071$	V_1	$s \times \cos E_1$	V_2	$s \times \cos E_2$
Y	$Y = V$	Y_1	$s \times \sin E_1$	Y_2	$s \times \sin E_1$
D	$D' + 2V$	D_1	$D' + 2V_1$	D_2	$D'_2 + 2V_2$
H	$\frac{D'}{2}$	H_1	$\frac{D'_2}{2}$	H_2	$\frac{D'_1}{2}$
P	$H - Y$	P_1	$H_2 - Y_2$	P_2	$H_2 - Y_2$
R	$b \times \cos F$	R_1	$b \cos F_2$	R_2	$b \times \cos F_2$

b is independent of tooth form, but usually from $\frac{1}{2}a$ to $\frac{1}{3}a$.

PROBLEMS IN DRAWING BEVEL GEARS

Miter gear. Draw a miter gear having a 5.000″ pitch diameter, 20 teeth, $1\frac{3}{8}$″ width of face, $3\frac{1}{2}$″ from apex of pitch cone angle to back of hub, $1\frac{1}{8}$″ bore, and $\frac{5}{16}$″ by $\frac{5}{32}$″ keyway. In cross-sectioning, show the gear as being made of machine steel.

Bevel gears. Draw a pair of bevel gears using the following information:

Number of teeth in the gear.....27
Number of teeth in the pinion.....15
Diametral pitch 3

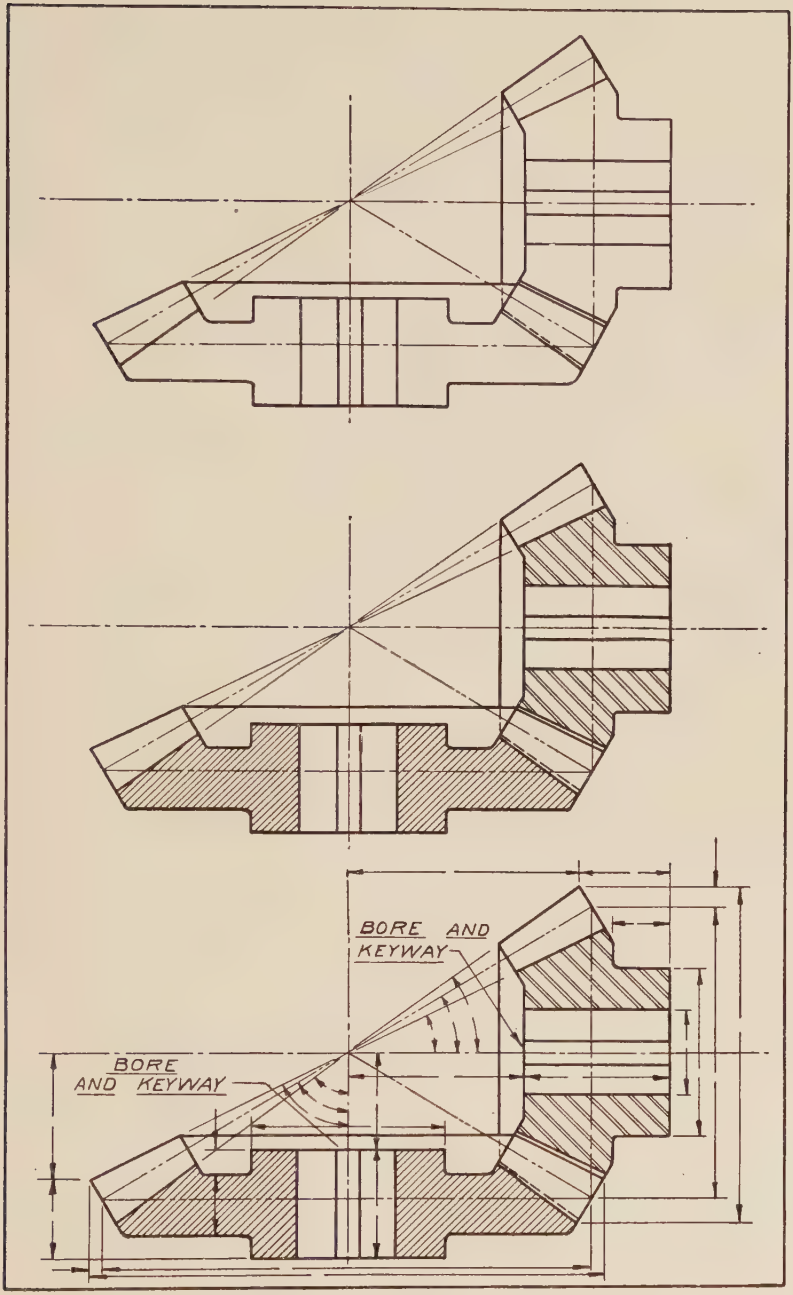


Fig. 80c

For the design of the hubs, refer to Figure 81 which is an incomplete drawing of the gears. Make the drawing in section. The gear should be made of bronze and the pinion of machine steel.

Worm Gears. Worm gears are used when considerable speed reduction is required, or when an increase in force is needed at a corresponding decrease in speed.

The shafts are usually at right angles, and do not intersect. The worm is placed on the shaft making the greatest number of revolutions and which is always the driving shaft.

The worm is simply a screw thread, a cross-sectional view of which is similar to the teeth in a rack. The calculations are made in the same manner as for spur gears. Due to the necessity for keeping the friction as low as possible, the diameter of the worm must be kept as small as possible.

Figure 52 may be referred to for proportions of worm threads.

The worm wheel is a gear on which the teeth are set at an angle equal to the lead angle of the thread of the worm. The teeth are cut with a hob, and are so shaped that they partly envelop the worm, thus giving a better contact than if the teeth were cut straight across.

Notation for Worm Gearing.

D' = pitch diameter of the wheel.
D = outside diameter of the wheel.
D'' = root diameter of the wheel.
T = throat diameter of the wheel.
N = number of teeth in the wheel.
d' = pitch diameter of the worm.
d = outside diameter of the worm.
d'' = root diameter of the worm.
n = number of threads in the worm (single, double, etc.).
F = face width of the wheel.
A = center distance.
L = number of degrees in the lead angle of the worm.
l = lead of the worm.
p' = circular pitch.
p = diametral pitch.
R = speed ratio.
W = working depth.
W' = whole depth.
c = throat radius.

$\emptyset$ = face angle.
t_n = normal thickness of tooth on the pitch line.

All other notations are similar to those for spur gears.

WORM AND WORM-WHEEL FORMULAS

$$D' = \frac{N\,p'}{3.1416} = .3183\,Np'$$

$$D = T + 2\,(e - e\cos\emptyset)$$

$$T = \frac{(N+2)\,p'}{3.1416} = .3183\,(N+2)\,p'$$

$$D'' = D - 2\,(s+f)$$

$$N = \frac{3.1416\,D'}{p'}$$

d' to be kept as small as possible

$$d = d' + 2s$$

$$d'' = d' - 2\,(s+f)$$

$$n = \frac{N}{R}$$

F = nearest fraction greater than $(2s + d')\sin\emptyset$

$$A = \frac{D' + d'}{2}$$

$$L \qquad \tan L = \frac{l}{3.1416\,d'} = \frac{.3183l}{d'}$$

$$l = p'\,n$$

$$p' = \frac{3.1416}{p}$$

$$p = \frac{3.1416}{p'}$$

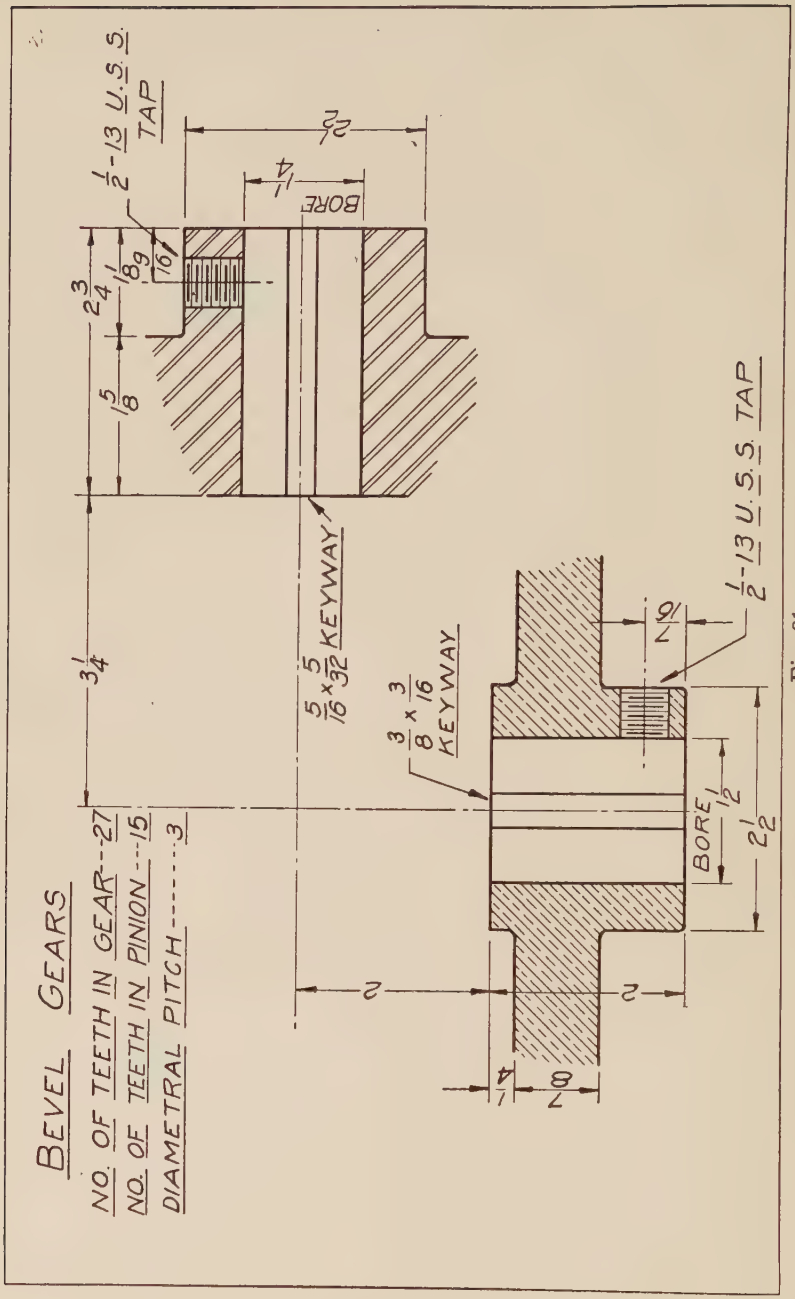

BEVEL GEARS
NO. OF TEETH IN GEAR---27
NO. OF TEETH IN PINION---15
DIAMETRAL PITCH-----3
1/2-13 U.S.S. TAP
BORE
2 1/2
2 3/4
1 1/8
1 5/8
3 1/4
5/16 x 5/32 KEYWAY
3/8 x 3/16 KEYWAY
1/2-13 U.S.S. TAP
BORE
2 1/2
2
2
1/4
7/8
1/2

Fig. 81

$$R = \frac{N}{n}$$

$$W = 2s$$

$$W' = 2s + f = .6866\,p'$$

$$c = \frac{d'}{2} - s$$

$$\text{Ø} = \text{from } 30° \text{ to } 45° \text{ but usually } 30°$$

$$t = \frac{p'}{2}$$

$$t' = t \cos L$$

Worm and Worm-Wheel Problems. Make a drawing of a worm and worm wheel using the following information:

Speed ratio ..... 45 to 1.
Circular pitch ..... .500″
Distance between shafts ..... 4.750″

Make the hub $2\frac{1}{4}$″ in diameter, $2\frac{1}{2}$″ long, bored to a diameter of $1\frac{3}{16}$″, with a keyway $\frac{5}{16}$″ wide and $\frac{5}{32}$″ deep. The web should be $\frac{3}{8}$″ thick, with cored holes to relieve the shrinking stresses. The rim should be at least $\frac{3}{8}$″ thick under the bottom of the teeth.

The worm must be sufficiently long to extend just beyond the point of last contact with the wheel.

Diametral Pitch Worm and Worm Wheels. Diametral pitch worm and worm wheels are also used, but due to the fact that the lead of the worm is difficult to cut on account of the gearing required, the circular pitch worms are generally used.

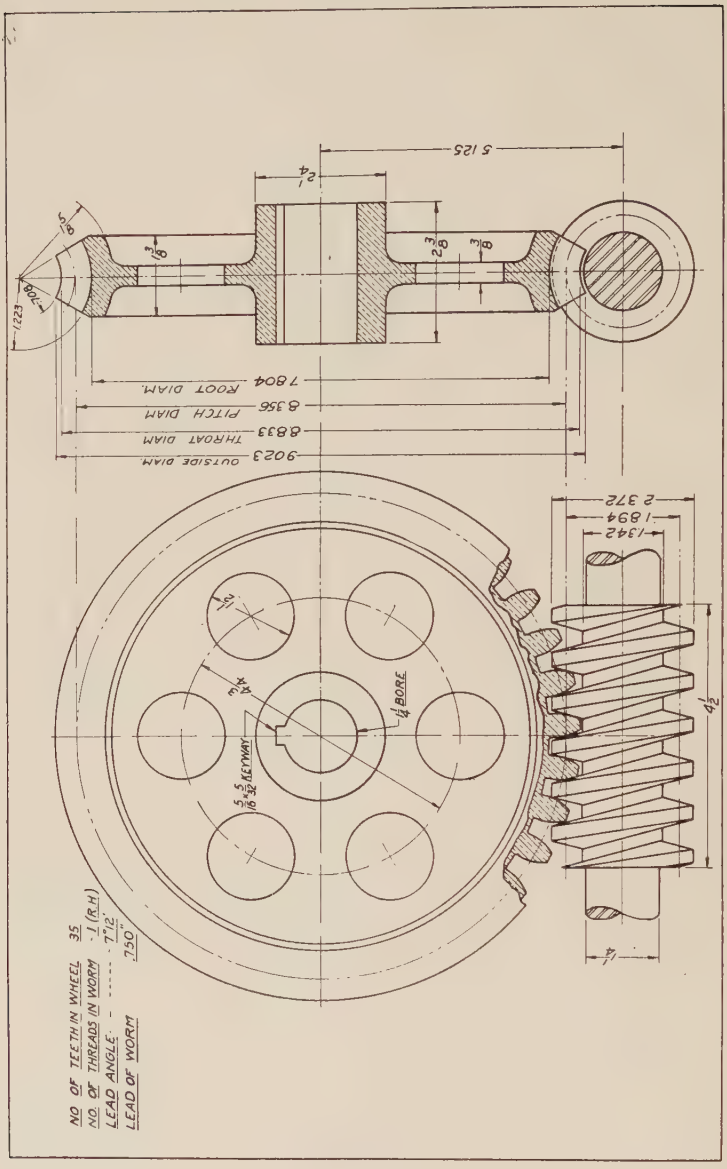

5 125
2 1/4
1/8
2 3/8
3/8
1/8
.708
.123
7804 ROOT DIAM.
8356 PITCH DIAM
8833 THROAT DIAM
9023 OUTSIDE DIAM
2 372
1894
1342
1/4 BORE
4 1/2
1/4
NO. OF TEETH IN WHEEL 35
NO. OF THREADS IN WORM 1 (R.H.)
LEAD ANGLE - 7°12'
LEAD OF WORM .750"

Fig. 82

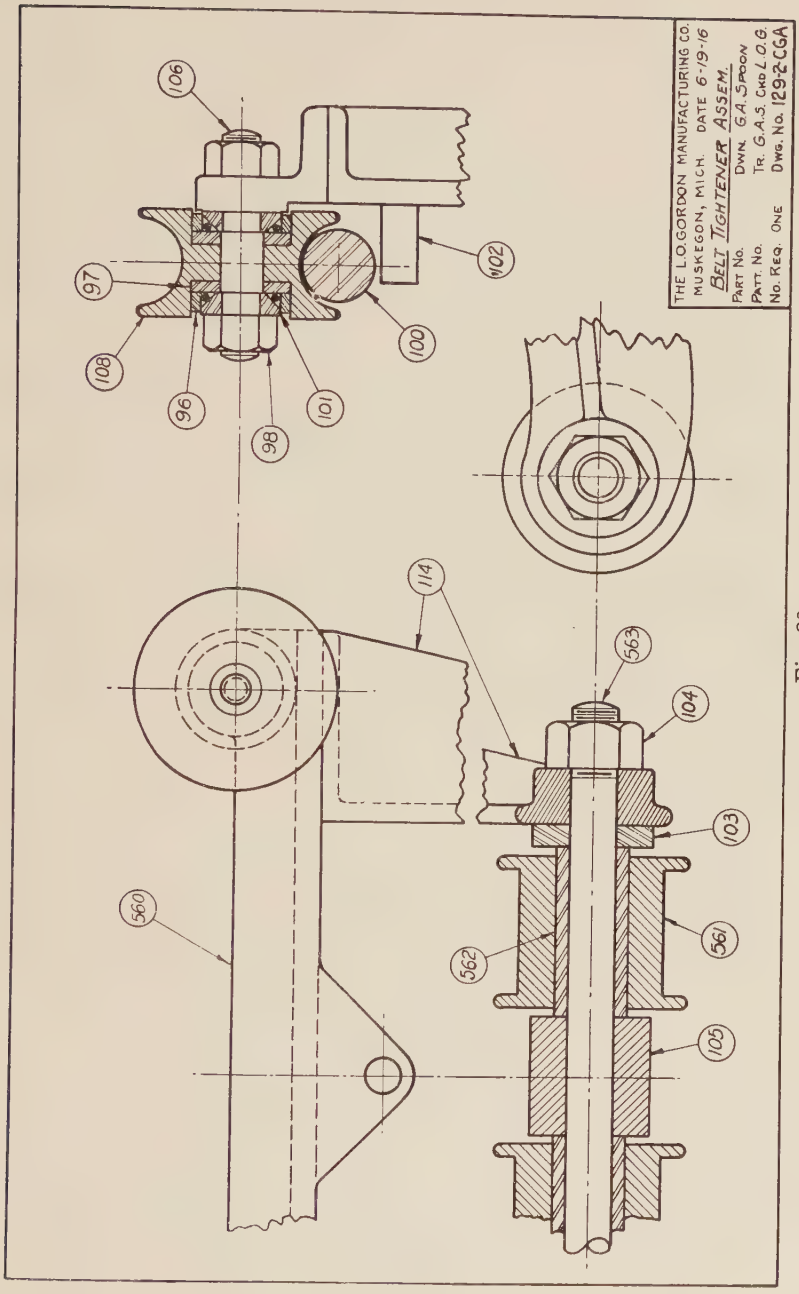

THE L.O.GORDON MANUFACTURING CO.
MUSKEGON, MICH. DATE 6-19-16
BELT TIGHTENER ASSEM.
PART NO. DWN. G.A.SPOON
PATT. NO. TR. G.A.S. CHD L.O.G.
NO. REQ. ONE DWG. NO. 129-2-CGA
106
97
108
96
98
101
100
102
114
563
104
103
561
105
562
560

Fig. 83

CHAPTER VI

ASSEMBLY DRAWINGS

Layout Assemblies. In the development of a design for a machine, a series of preliminary sketches and calculations are followed by an assembly, or what is known as the "layout assembly" drawing.

The layout assembly drawing is the first scale drawing of the machine, and is made to as large a scale as the draftsman's board will permit. This is done to judge more accurately the proportions of the various parts of the machine. The layout assembly shows all of the parts of the machine in their proper working positions and in relation to each other. This is the drawing from which the detail drawings are made.

Working Assemblies. After the details of the machine have been drawn, it becomes necessary to make a new assembly drawing for the purpose of checking the details, as probably many changes have been made in the machine during the making of the detail drawings. Possibilities for improvement of the original design usually appear at the time that the details are being made.

If possible, a draftsman who has not done part of the detailing should make the new assembly drawing. He would be more likely to find missing dimensions and discrepancies in the details than if he had drawn the details himself.

This drawing, when complete and approved by the chief draftsman, is traced, and prints from it are sent into the shop to serve the men who assemble the machine.

Subassemblies. Many types of heavy machines are assembled by units. This is true of road building and excavating machines and also of many other types of machines. In manufacturing plants where such machinery is built, there will be found assembly drawings of these individual units. They are not complete assembly drawings, as the whole machine is not on one drawing, but are called "subassembly" drawings.

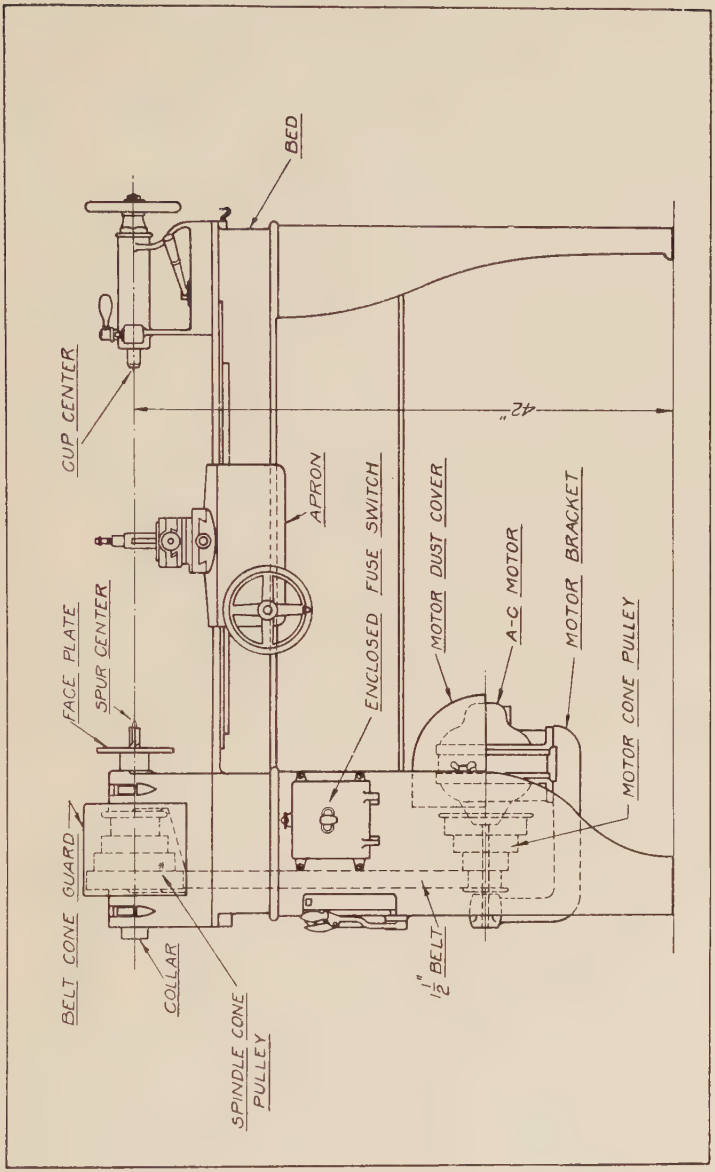

BED
CUP CENTER
42"
APRON
ENCLOSED FUSE SWITCH
MOTOR DUST COVER
A-C MOTOR
MOTOR BRACKET
FACE PLATE
SPUR CENTER
MOTOR CONE PULLEY
BELT CONE GUARD
COLLAR
SPINDLE CONE PULLEY
1/2" BELT

Fig. 84

A machine, such as a drag line, would have to be assembled by units, and would require several of these subassembly drawings. Drawings of such units as the caterpillar, the frame, the steam or gasoline power plant, the drag drums and controls, the cab, and the boom and the bucket would be required on the assembly floor from which the men could work.

Figure 83 is an illustration of a gravity belt tightener in use on cam grinding machines. This is an example of a subassembly drawing as it illustrates only one of the units which compose this machine. Separate drawings are made for the bed, the headstock, the tailstock, the cross slides and grinding head, the countershaft and belt drum.

Sales-Engineering Assemblies. Assembly drawings also are made for use by salesmen and for catalog illustrations. This type of assembly often is incomplete, and does not show all of the parts of the machine, but only enough to give a prospective buyer the main points of the machine and particularly those of selling interest. Many buyers of machines are not technically trained, and a complete assembly drawing would do more to confuse them than it would be of service in selling the machine. Thus, these drawings must be made simple enough to be readily understood by men who are not acquainted with mechanical-drawing methods. This type of assembly is called a "sales-engineering" assembly.

Figure 84 is a sales-engineering assembly of a lathe. It does not show the complete assembly drawing, indicating the exact location of each part of the machine, but only those parts which would be of interest to a prospective purchaser. It gives the main over-all sizes of the machine required by the purchaser, in this case the distance from the work center to the floor.

Set-up Assemblies. When a machine is sent to its destination, still another type of assembly drawing accompanies it, called the "set-up" assembly. The millwright uses this drawing in locating the bolts which are to hold the machine to the floor, and the location of the countershaft if the machine requires one. In addition to this information, the set-up assembly should state the number of revolutions of the shaft to

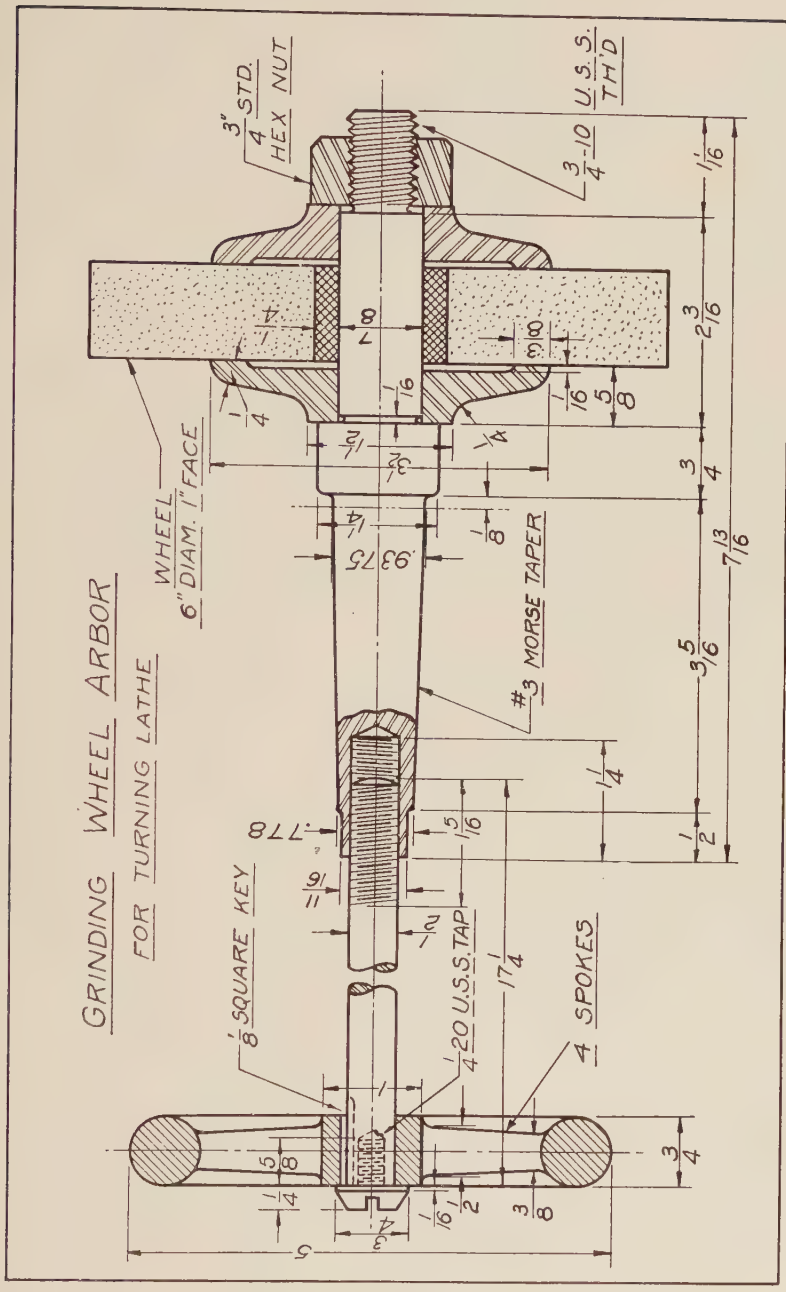

GRINDING WHEEL ARBOR
FOR TURNING LATHE
WHEEL
6" DIAM. 1" FACE
3" STD. 4 HEX NUT
3/4-10 U.S.S. TH'D
#3 MORSE TAPER
.9375
.778
1/8 SQUARE KEY
1/4-20 U.S.S. TAP
4 SPOKES

Fig. 85

which the power is to be applied, so that the millwright will be able to calculate the size of the pulley for the line shaft from which the machine receives its power. The power required to run the machine should also be stated on this drawing, so that the millwright may be able to decide intelligently the required strength of belting necessary for the operation of the machine.

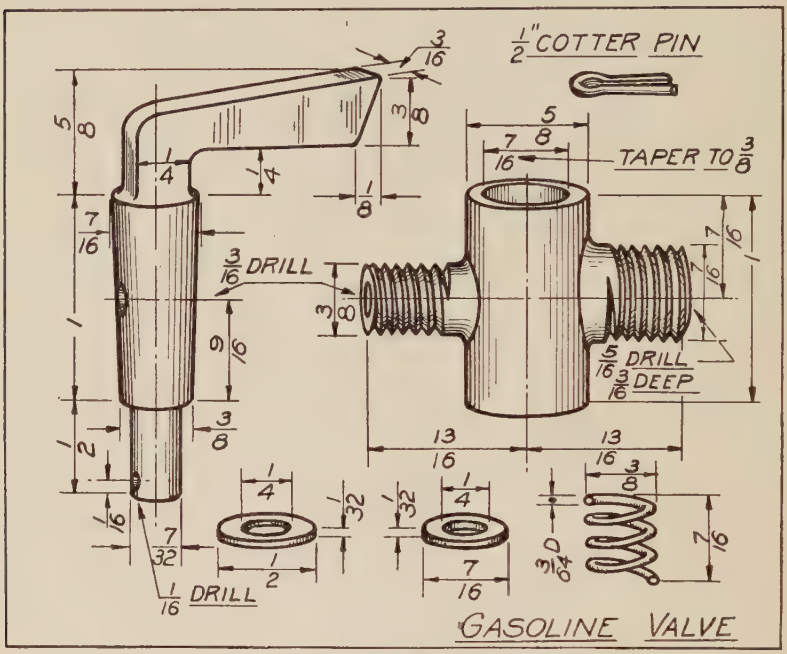


Fig. 86

Dimensioned Assemblies. In very simple machines or attachments, it is sometimes possible to dimension the assembly drawing, and to make detail drawings of the pieces unnecessary. This is allowable only when the piece being drawn is to be made only once, or at best only a very few times. On a high production order, however, too much time would be lost by the machinists in picking out the proper dimensions.

When a dimensioned assembly drawing is made, each piece should be dimensioned fully before another is begun.

Figure 85 is a drawing of this type. It shows a grinding-

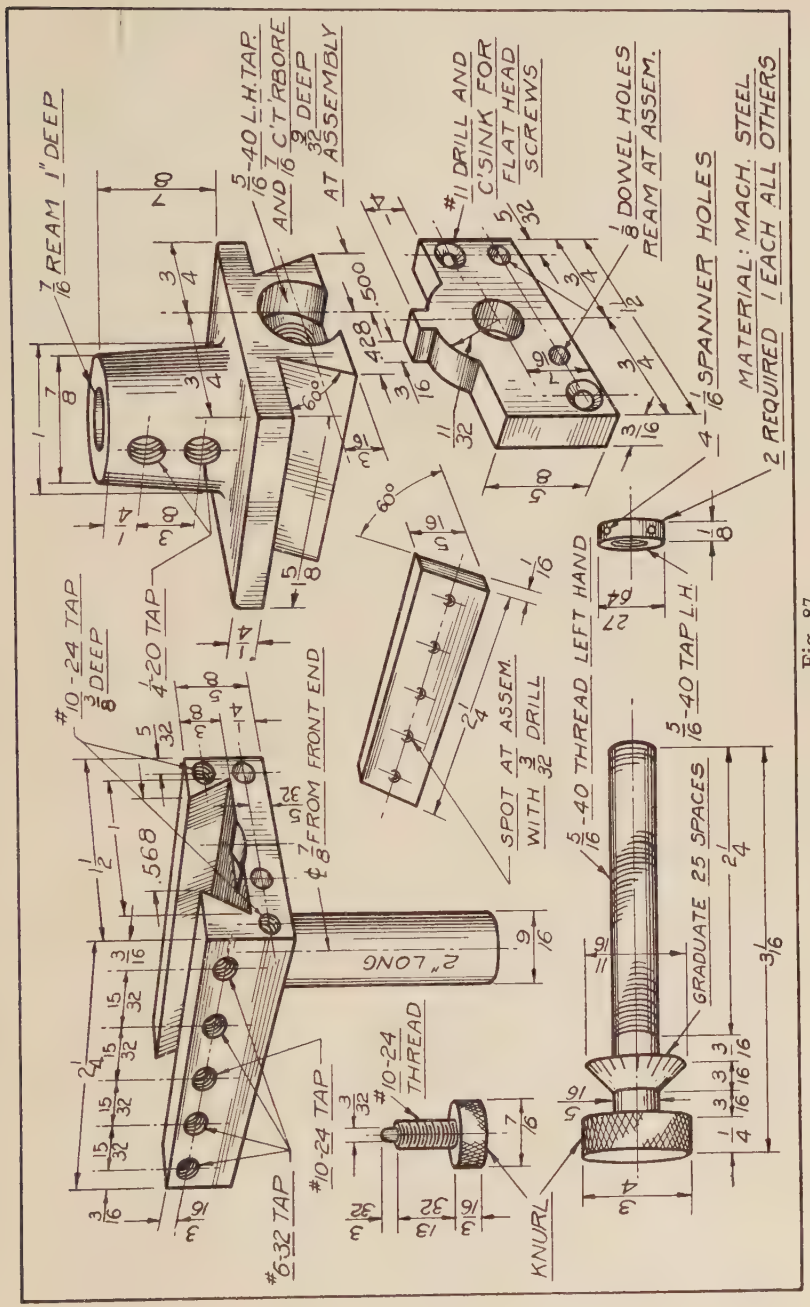

7/16 REAM 1" DEEP
5/16-40 L.H. TAP AND 7/16 C'BORE 3/32 DEEP AT ASSEMBLY
#11 DRILL AND C'SINK FOR FLAT HEAD SCREWS
1/8 DOWEL HOLES REAM AT ASSEM.
4 1/16 SPANNER HOLES
MATERIAL: MACH. STEEL
2 REQUIRED 1 EACH ALL OTHERS
#10-24 TAP 3/8 DEEP
4-20 TAP
7/8 FROM FRONT END
SPOT AT ASSEM. WITH 3/32 DRILL
5/16-40 THREAD LEFT HAND
5/16-40 TAP L.H.
#6-32 TAP
#10-24 TAP
#10-24 THREAD
KNURL
GRADUATE 25 SPACES
2" LONG

Fig. 87

wheel arbor which is to be put into the spindle of a speed lathe, held in place by the use of a drawbar through the opposite end. The arbor, the drawbar, the washers, the handwheel, and the special screw used to hold the handwheel in place are dimensioned on this drawing. The grinding wheel is specified and is purchased according to these specifications, no drawing being required. The $\frac{3}{4}''$ standard hexagon nut also needs no dimensioning, as it is merely requisitioned from stock for the work, and is not made together with the rest of the attachment.

Gasoline Valve. Figure 86 illustrates a small valve which is used between the gasoline tank and the mixing valve on an outboard rowboat motor. Each part is fully dimensioned.

This is to be used both as a problem in detailing and as an assembly drawing. Using a B-size sheet, all the details and the assembly may be placed on one sheet. The threads on the ends of the body are standard threads and not pipe threads. The plug should be drawn showing the handle before it is bent, and hidden lines should show how it is to be bent after it has been machined. The cotter pin need not be detailed, but must be "called for" on the assembly by a leader and the note, "$\frac{1}{2}''$ cotter pin." The entire valve is made of bronze; the cotter pin and spring are of steel.

45 Deg. Angle Valve. At various points in the foregoing chapters, all the parts of an angle valve have been mentioned and supposedly drawn in detail. These details should now be used in making the assembly drawing. The valve is composed of the following parts:

Body (lower half)	Figure 45.
Body (upper half)	Figure 46.
Seat	Figure 34.
Disc	Figure 60.
Lock nut	Figure 59.
Bonnet	Figure 56.
Packing gland	Figure 33.
Packing-gland studs	No Figure.
Stem	Figure 55.
Handwheel	Figure 40.
Standard hexagon nuts, 7 required	No Figure.
Hexagon head bolts, 10 required	No Figure.

In making the working assembly of this valve, only one view

will be required, provided that it is made a sectional side view. This will show each piece to the best advantage. It should be remembered in drawing this assembly that the stem and the studs must not be sectioned. The nuts on the gland studs and the nut which holds the handwheel in place should not be sectioned, although they will be cut by the plane of the section.

The valve disc should be shown faced with babbitt, to a thickness of $\frac{3}{4}''$ and held in place by the dovetail groove in the face of the disc itself.

Boring Chuck. The boring chuck, all the parts of which are illustrated in Figure 87, is another problem well adapted to both detail and assembly drawing. It is suggested that in this problem each piece be drawn on a separate sheet according to the plan generally used for high production work. The assembly should be made in two views and the tool bit (not shown in the figure) may be shown in the $\frac{7}{16}''$ socket, held in place by two headless setscrews in the body of the tool holder.

Note in the illustration that the screw has 40 threads per inch and that the head of the screw is graduated into 25 divisions, so that each graduation of the tool is, in reality, in thousandths of an inch. Thus, each movement of one space on the dial causes a movement of .001″, either toward or away from the center of the hole being bored. The parts of the chuck are made of machine steel, and should be hardened to withstand wear without causing any inaccuracy in the work. This must be indicated on the drawing.

Screw Punch. The screw punch and frame, illustrated in Figures 57 and 58, can be used for making an assembly drawing. The assembly drawing can be made either from the illustration in the book or from the working drawings made by the students.

The assembly drawing should be made full scale, and the front and side views should be drawn on a C-size sheet of drawing paper. If it is desired to make this a dimensioned assembly, it will be necessary to add a view in which the shape of the base and the H part of the frame will be shown. If it is to be made a regular shop assembly without dimensions, it will not be necessary to make sectional views.

CHAPTER VII

ADVANCED DETAIL DRAWINGS

The principal methods for expressing the shape and size of an object or a machine part have been discussed in previous chapters, so that the drawings thus made will serve as a guide to the many craftsmen who may have to take part in its construction. No mention has thus far been made of the treatment which the piece must undergo, or which of its surfaces must be machined, so that the finished piece will function properly on the machine.

Finish. When reference is made to the machining of any surface on a machine part, it is generally called "finish." This refers to such operations as turning, planing, shaping, boring, drilling, grinding, and all other methods by which some of the metal is removed from the surface of a machine part, in order to bring it to its proper size, and to remove the scale which forms on it when it is cast in the foundry.

If a drawing were sent to the pattern shop without any indication as to whether it is to be machined or not, the patternmaker would not make any allowance on the pattern. The casting made from it, therefore, would not have sufficient extra metal for machining through the scale, and when completed, it would be smaller than the specified size.

When a surface indicated on a drawing is to be machined, the view in which this surface shows as an edge is marked with the letter *f*, or a slight variation of it. The main stroke of the letter should lie across the line, which indicates the position of the surface, and the second, or cross stroke, should be placed at the same intersection. In this way there will be no confusion where several lines are close together, any one of which might be interpreted as the one to which the finish mark refers, if the *f* were not crossed properly.

When a piece is to be completely machined, it is not neces-

sary to place finish marks on each separate surface. In such a case, a note "finish all over" or its abbreviation "F.A.O." is placed on the drawing.

Degree of Finish. When a certain degree of finish is desired, it is common practice to place a note to this effect near the finish mark. Such expressions as "turn," "rough grind," "finish grind," "disc grind," "polish," and many other degrees of finish are indicated by this method.

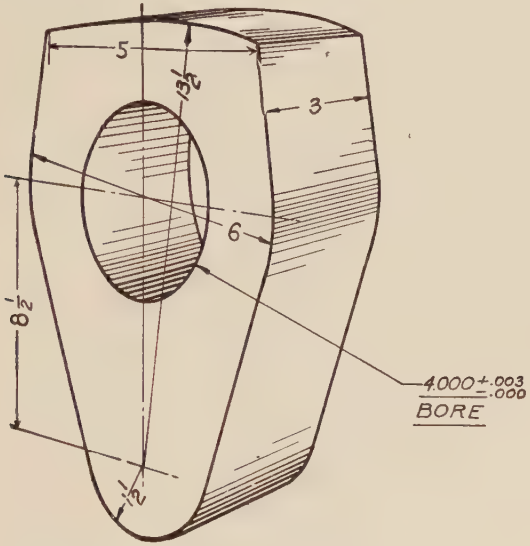


Fig. 88. Oscillator

Accuracy of Finish. To obtain the right amount of difference between pieces which are to run together on a machine, "tolerances" or limits are placed on the dimensions. This makes certain that the pieces, when finished, will not be too tight nor too loose for the purpose for which they were designed. The amount of leeway given a machinist is placed on a drawing immediately behind the dimension affected. Thus, a dimension which may be .003″ larger than the stated dimension, and only .001″ smaller, will be indicated on a drawing as follows:

$$\langle \text{———} 3.000 \begin{matrix} + .003 \\ - .001 \end{matrix} \text{———} \rangle$$

When working to these tolerances, the machinist's work is satisfactory if the dimension of the finished piece is between 2.999″ and 3.003″. These are referred to as the limits on a drawing. When it is customary for all dimensions to have a certain amount of tolerances, unimportant surfaces are not given individual tolerances, but are covered by a "blanket note" something on this order: "Unless otherwise specified, all dimensions are to be $\pm$ .010″. In the following drawings, attention is called to surfaces and entire pieces which are to be machined.

The following problems are given with a view to broadening the various principles covered in the previous chapters, and to let the student work them out in more difficult drawings.

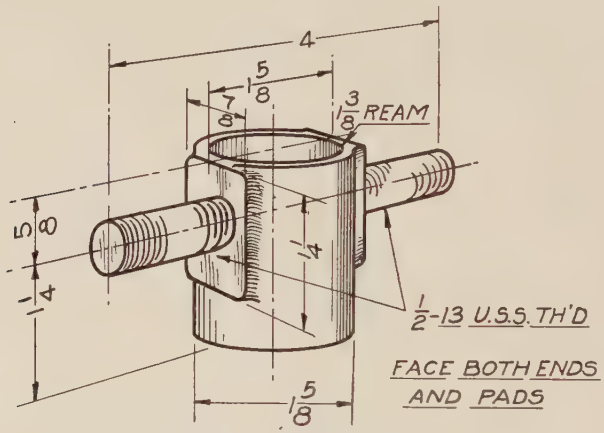


Fig. 89. Drive-Shaft Support

Oscillator. Figure 88 illustrates the oscillator in the head of a power-driven punch press. It must withstand a constantly recurring shock, and, consequently, it must be made of alloy steel capable of doing the work satisfactorily. It must be finished all over, and the drawing must state this in a note. The tolerances on the hole must be placed on the dimension as discussed. A complete working drawing of this piece can be made in two views.

Drive-Shaft Support. The rowboat-motor drive-shaft sup-

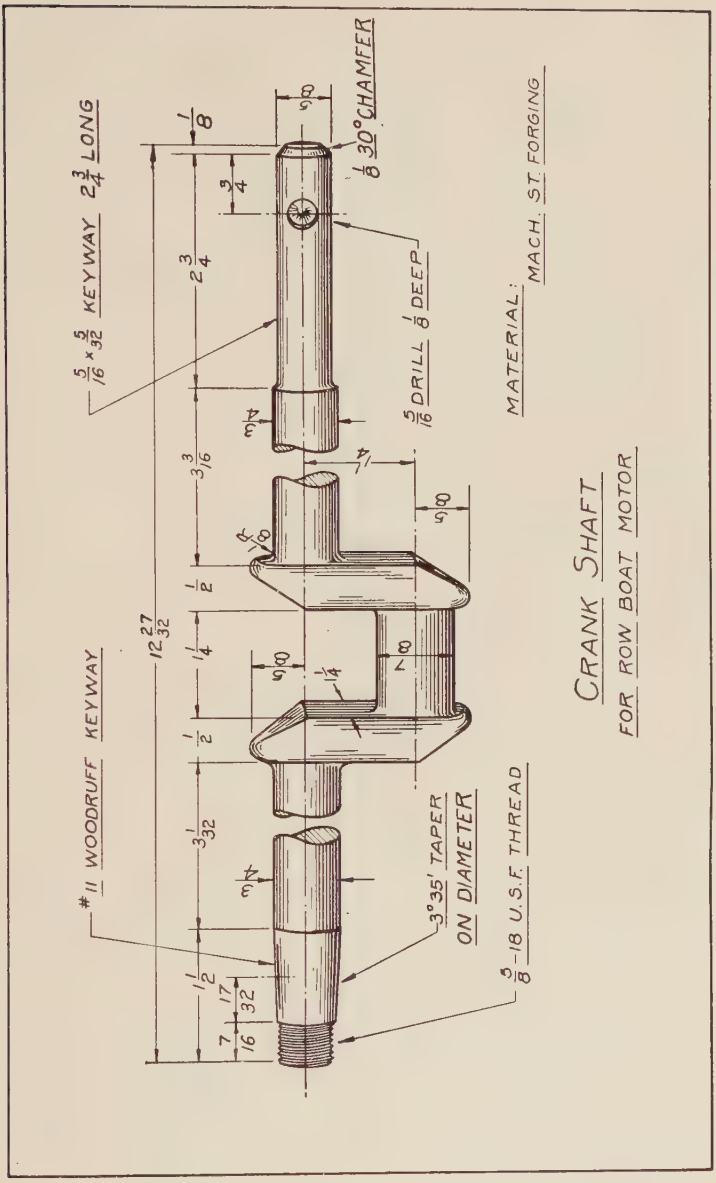

5/16 × 5/32 KEYWAY 2 3/4 LONG
1/8 @ 30° CHAMFER
5/16 DRILL 1/8 DEEP
#11 WOODRUFF KEYWAY
3° 35' TAPER ON DIAMETER
5/8-18 U.S.F. THREAD
MATERIAL: MACH. ST. FORGING
CRANK SHAFT
FOR ROW BOAT MOTOR

Fig. 90

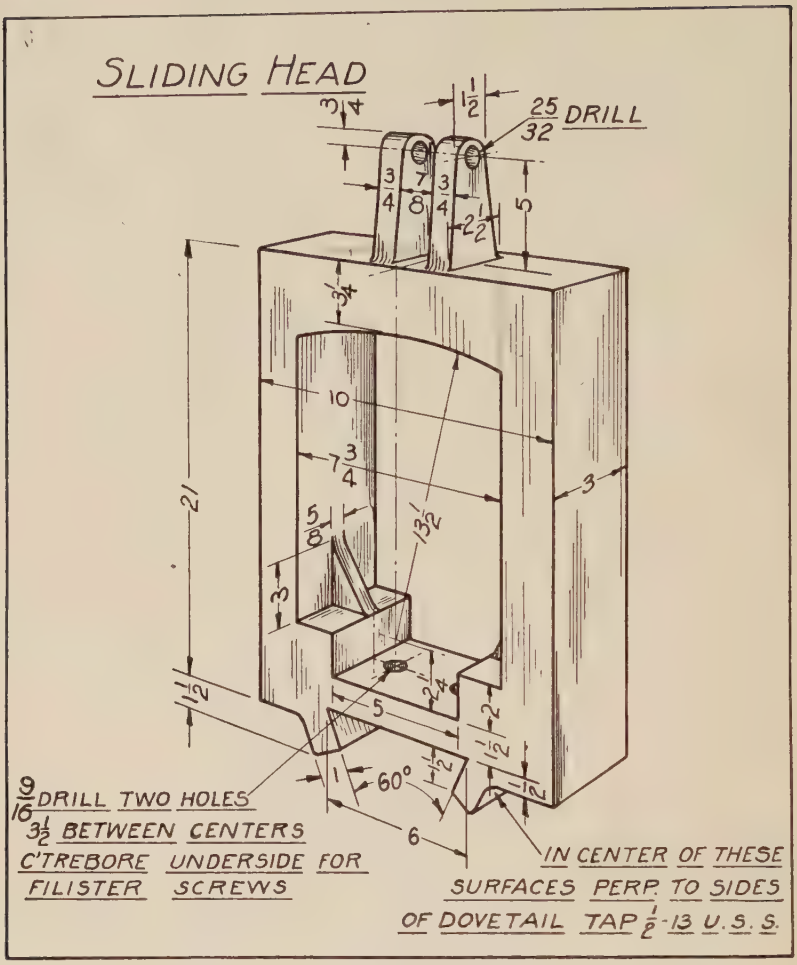


Fig. 91

port, illustrated in Figure 89, is made of cast bronze. The hole must be reamed, the ends faced, the projecting parts turned and threaded, and the adjacent surfaces machined. These required operations must be taken care of by finish marks and by notes.

In making the detail drawing, three views will be required.

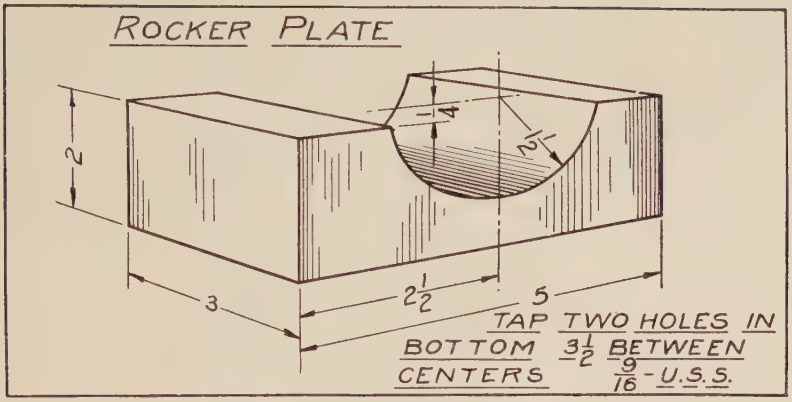


Fig. 92

Crankshaft. The crankshaft, Figure 90, is made of forged steel, and must be completely machined with the exception of the crank arms. The drawing must include the finish marks,

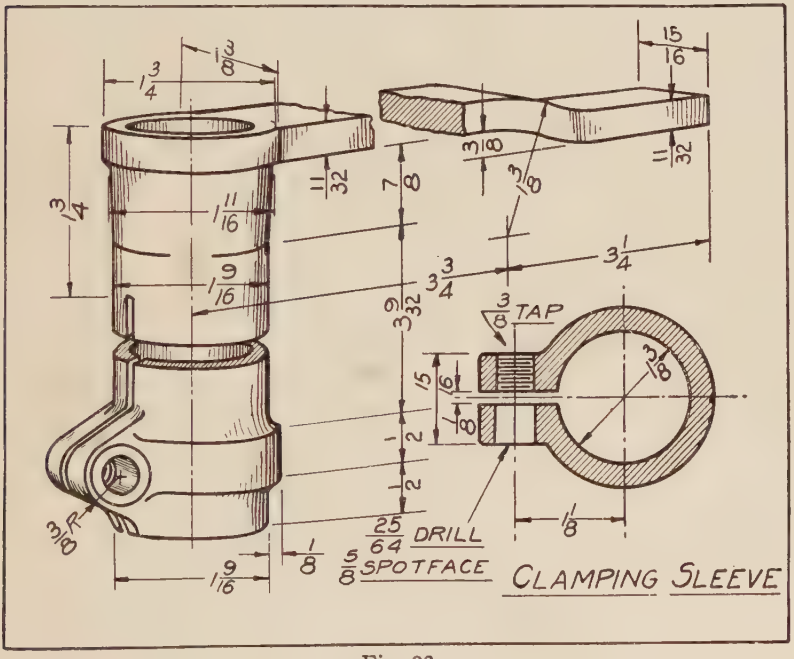


Fig. 93

which will tell the die sinker to make sufficient allowance on the die, so that the piece will clean up when it is being machined. The crank arms should be finished on the inside surfaces only.

In order to obtain the necessary information to draw the No. 11 Woodruff keyway, reference must be made to one of the standard handbooks. The drawing should be made full size on a B-size sheet of drawing paper. It will be noticed that the piece is longer than the paper. Therefore, in order to draw the two required views, it will be necessary to show conventional breaks at two places, so that the view may be shortened sufficiently to go on the paper.

Punch-Press Sliding Head. Figure 91 shows the sliding head of a power-driven punch press. Note the relation between this figure and Figure 88. By placing the oscillator with its $13\frac{1}{2}''$ radial surface against the corresponding surface on the slide, space will be left for the rocker plate which is illustrated in Figure 92. This plate is made of hardened steel to take the load from the oscillator to the punch, and to stand the wear caused by the rocking motion of the oscillator. The dovetail slot at the lower end must be made to fit the punch holder and punch illustrated in Figures 28 and 29. The radial surface, the position for both the rocker plate and the punch holder, and the four outside surfaces must be machined, and should be so indicated on the drawing.

Clamping Sleeve. The clamping sleeve, Figure 93, should be drawn in two views, full size on a B-size sheet of drawing paper. The only section required will be a revolved section on the handle. The "spotface" on the drawing means that a hole $\frac{5}{8}''$ in diameter must be cleaned through the scale, to form a perfect seat for the head of a special bolt which fits into this hole. The handle is tapered its entire length. The detail given in the lower right-hand corner is used to make more clear the construction at the lower end of the sleeve.

Gasoline-Tank Bracket. Figure 94 illustrates the gasoline-tank bracket on a motor, many parts of which have been detailed previously in the course. In drawing this bracket, two full views are required and some sections, taken preferably at

the points where the breaks are shown in the figure. A full-scale drawing can be made on a B-size sheet of drawing paper. The bracket must be made of cast iron finished only on the underside of the three circular pads. These pads should be tapped for screws, to come up through both halves of the crankcase when the motor is being assembled.

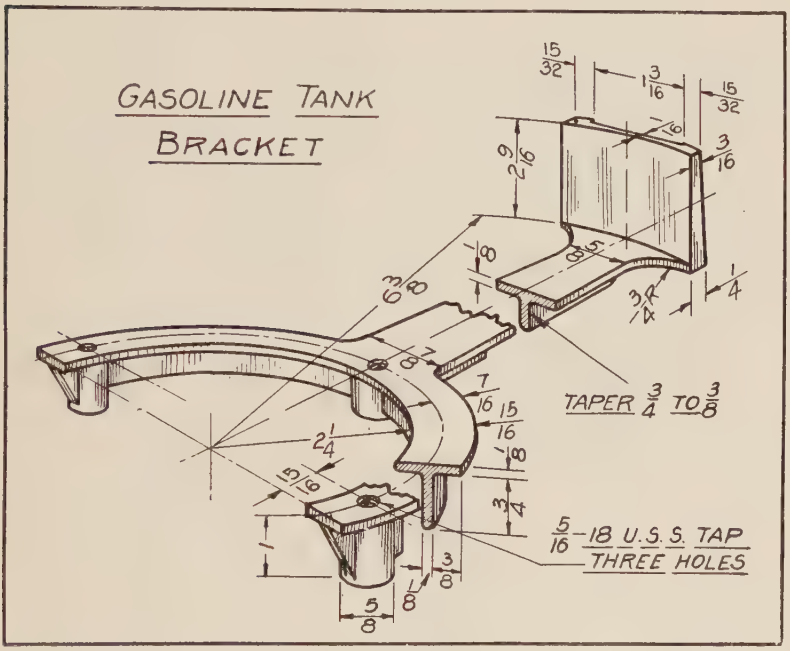


Fig. 94

Tilting Guide. Figure 95 shows the tilting guide used on a motor. This drawing shows the method to be used when it is necessary to draw the arcs of a circle if the radius is given but not the center. In order to find the center of the $8\frac{9}{16}$" radius, it is necessary to set the compass at the required radius. Then, with the needle point of the compass at the point known to be the right end of the arc, swing another arc across that part of the drawing in which the point is supposed to lie. To intersect this arc, another is drawn from

the center point of the $\frac{3}{4}''$ radius, at the opposite end of the guide. The radius of this arc must be equal to the required radius plus the $\frac{3}{4}''$ radius, or a total of $9\frac{5}{16}''$. The intersection of these two arcs is the center of the required arc.

The drawing of the guide may be made on a B-size sheet of drawing paper to a full scale, if some of the centers are al-

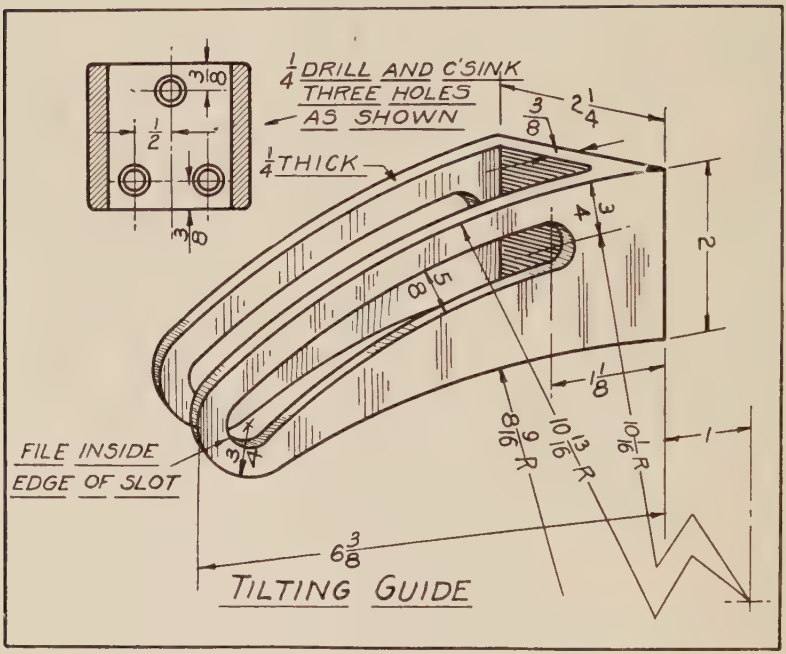


Fig. 95

lowed to fall outside the limits of the drawing. The centers are then located as shown in the figure. This method is often referred to in the shops as "lightning," due to the sharp breaks in the direction of the line.

Pump Housing. The pump housing, Figure 96, is an application of the principle just discussed, with the exception that both of the ends of the arc are definitely determined, and from these two points intersecting arcs of the required radius may be drawn to locate the center point. The fifteen $\frac{3}{32}''$ holes shown in the drawing are not definitely located, but must be

placed close together and within $\frac{1}{4}$" of the center line drawn through the group of holes. Two separate views of the housing are illustrated, each showing one side.

The drawing is best made in three views. Care must be taken in placing these views, as each side view must be on its proper side of the end view.

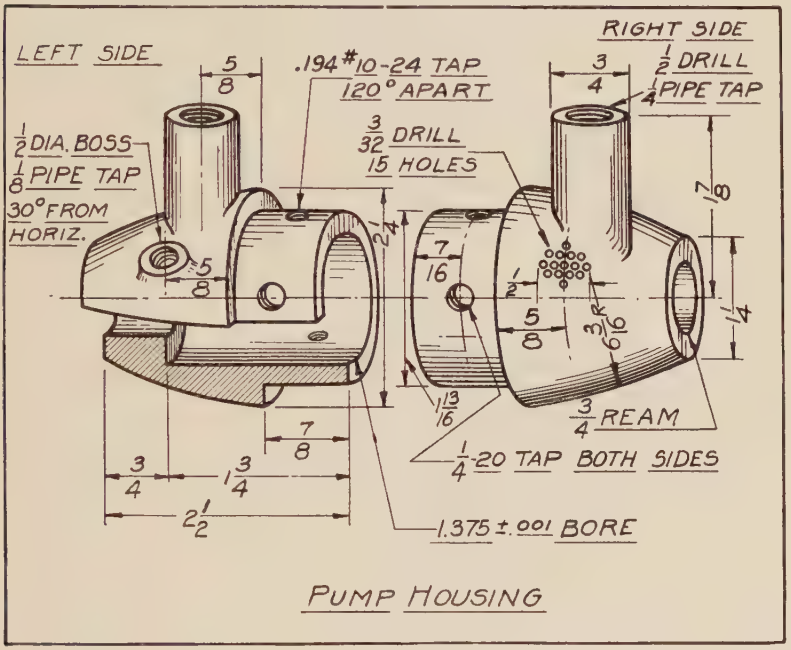


Fig. 96

Flywheel. The detail drawing of the flywheel, Figure 97, may be made in two views: top view, and front sectional view. These two views should be supplemented by a small auxiliary view through the web, on a line through the centers of two of the cored holes.

Great care must be exercised in locating the nose of the cam on the hub, the keyway in the hole in the hub, and the counterbalance on the inside of the rim. Accurate work is necessary if the motor is to be kept as free from vibration as possible. The diameter of the tapered hole may be found by referring

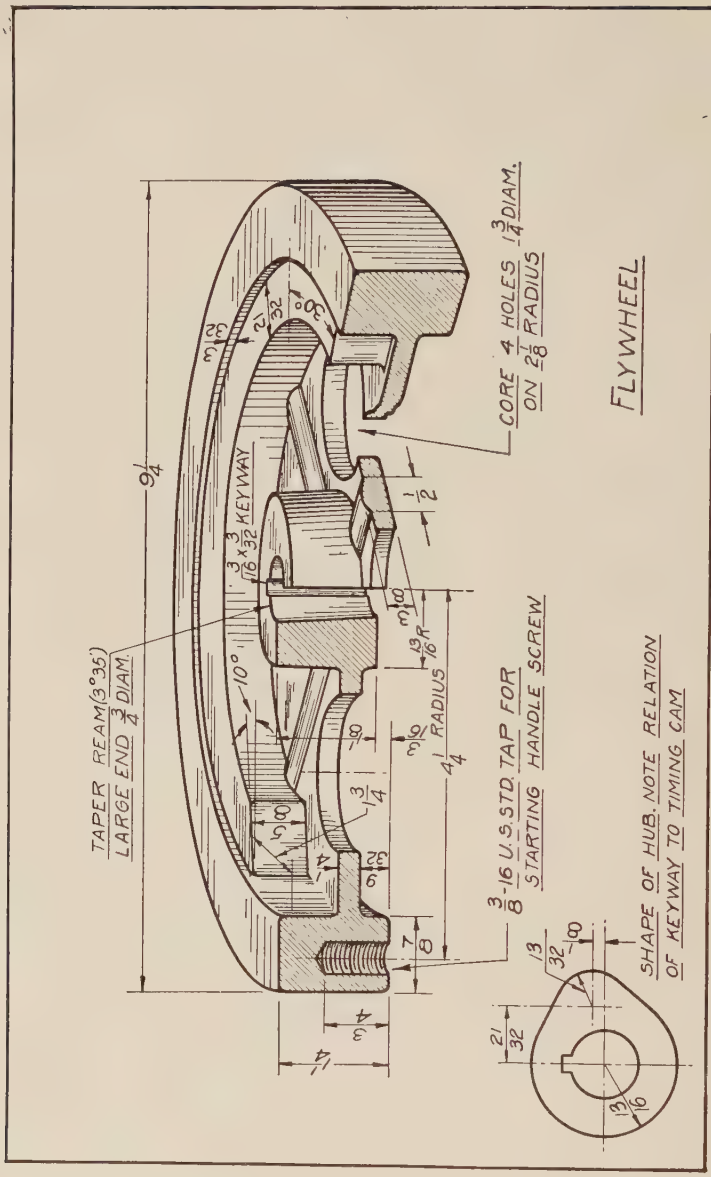

FLYWHEEL
CORE 4 HOLES 1 3/4 DIAM. ON 2 1/8 RADIUS
TAPER REAM (3°35') LARGE END 3/4 DIAM
3/8-16 U.S.STD. TAP FOR STARTING HANDLE SCREW
SHAPE OF HUB. NOTE RELATION OF KEYWAY TO TIMING CAM
3/16 x 3/32 KEYWAY
4 1/4 RADIUS
9 1/4
10°
30°

Fig. 97

to Chapter VIII, on the solution of triangles, and solving for the short leg of a triangle whose long leg is equal to the length of the hub and one of the acute angles of which equals $\frac{3° 35'}{2}$. Twice this result must be subtracted from the diameter at the large end, because the taper refers to the angle of the side of the hole with the center line. The flywheel should be made of cast iron. The parts to be machined are the ends

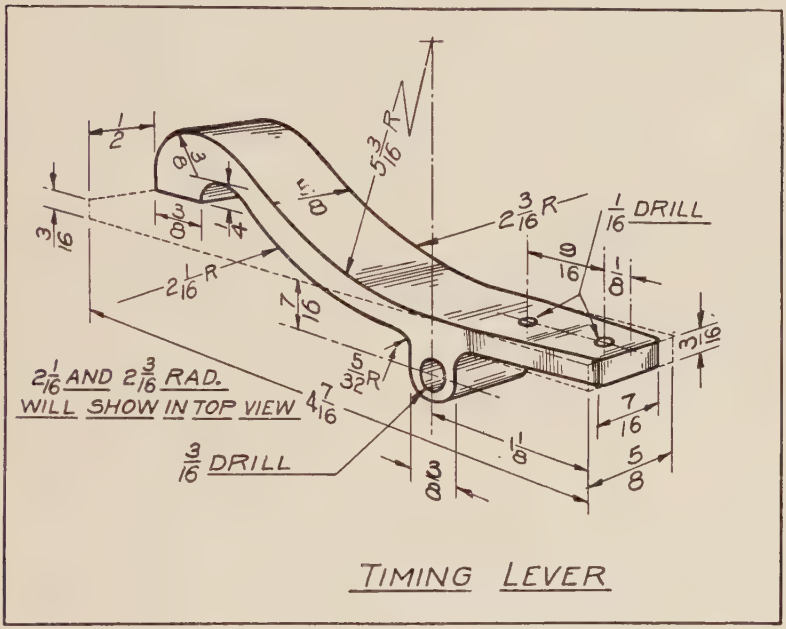


Fig. 98

of the hub, the hole in the hub, both faces of the rim, and the outside diameter. In the illustration, the flywheel is turned to show the bottom because that side involves more detail.

Timing Lever. Figure 98 shows the timing lever which works against the cam on the hub of the flywheel just discussed. Due to the offset, it is somewhat difficult to draw, but

is placed here more as a problem in visualizing than in drawing. The dotted lines in the drawing show the amount of the offset.

In making the detail drawing of the piece, only two views will be required. These may be drawn easily on an A-size sheet of drawing paper.

Connecting Rod. In Figure 99 is shown the connecting rod of the motor. Due to the fact that the rod and the cap are partly machined before being cut apart, they are drawn on

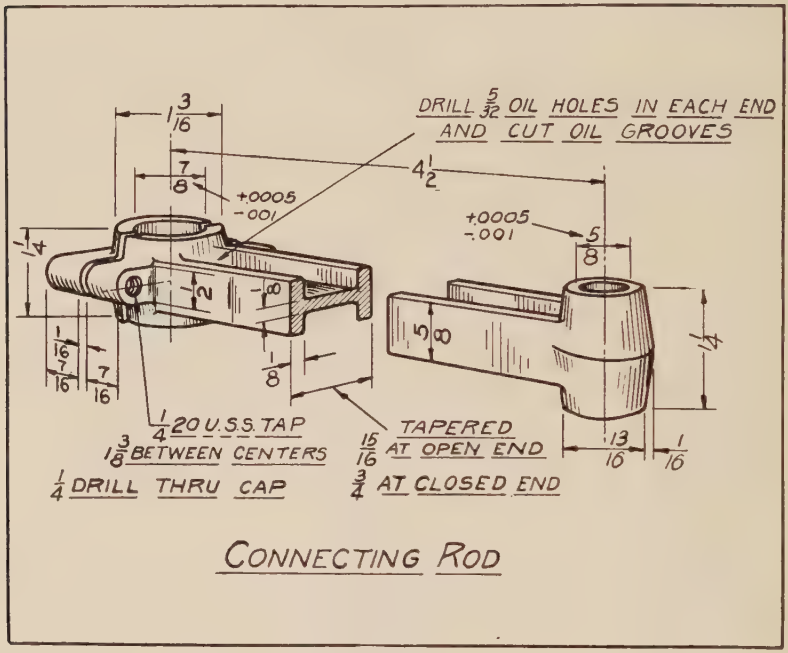


Fig. 99

one sheet of paper. Two views and a revolved section must be made of the rod, while the corresponding views of the cap must be made in the same relation that they appear to each other in position on the motor. In addition to this, a view showing the top of the cap and the location of the cap screw-holes is necessary.

The rod and cap should be shown on the drawing $\frac{1}{16}$″ apart, each part $\frac{1}{32}$″ from the center line of the hole. The center of the hole remains at the center line, the $\frac{1}{16}$″ of metal being cut away after the hole has been machined to size.

The oil grooves indicated in the figure should be $\frac{1}{16}$″ wide

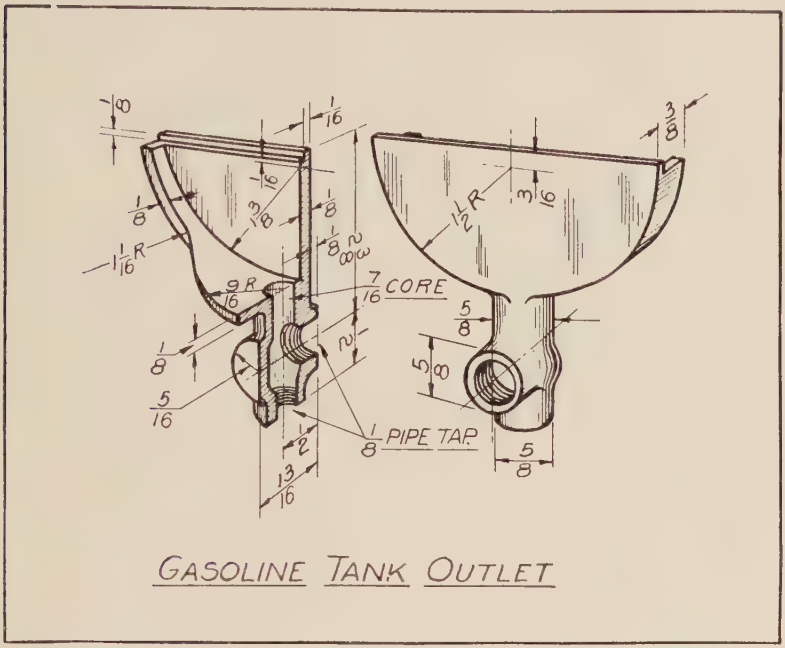


Fig. 100

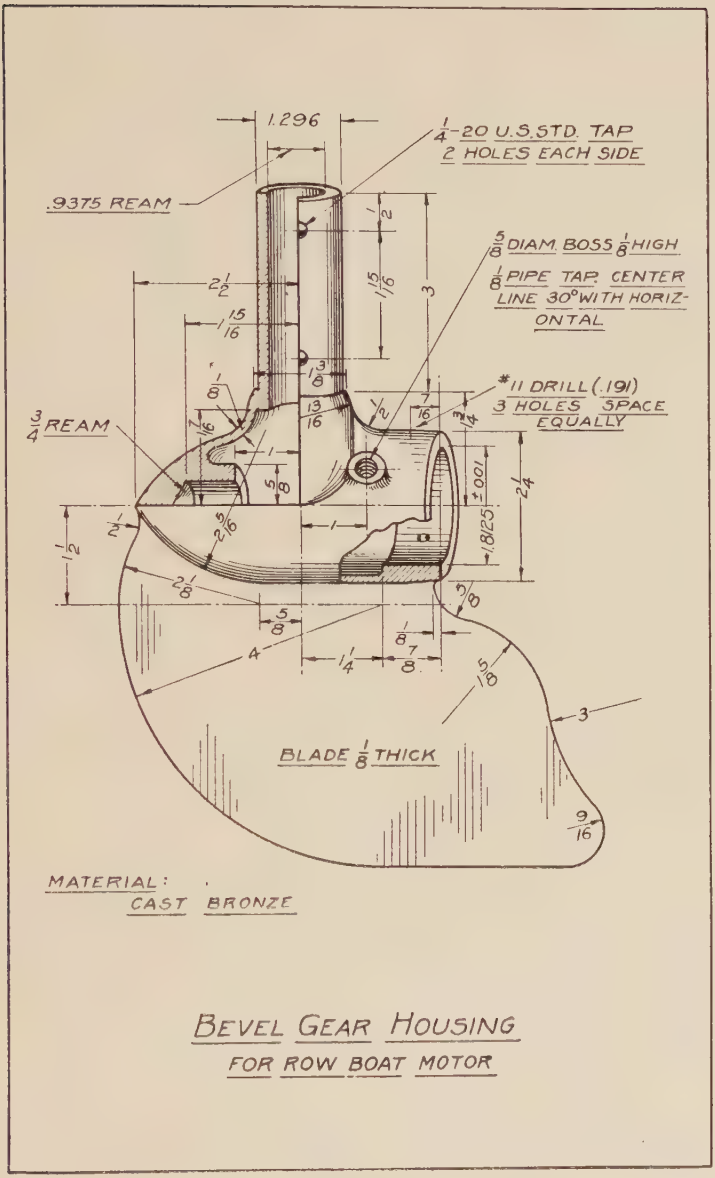
and $\frac{1}{32}$″ deep, and should come within $\frac{1}{8}$″ of the ends of the bearings.

Gasoline-Tank Outlet. The gasoline-tank outlet, Figure 100, is given as a problem in drawing pipe threads. One sectional view should be included in the detail drawing, preferably in the same position as the one illustrated. To obtain the information required for drawing the pipe threads, it will be necessary to refer to the section on pipe threads in Chapter IV. The drawing can be made easily on an A-size sheet of drawing paper.

REVIEW AND EXAMINATION PROBLEMS

The following illustrations, the bevel-gear housing, Figure 101, the crankcase upper half, Figure 102, the crankcase lower half, Figure 103, the cylinder, Figures 104 and 104*a*, the screw-press, Figure 105, and the punch-press frame, Figure 106, are all somewhat complicated, and form a very good group of problems for selection at the end of the course, both for review and for examinations. The work may cover from four to six hours, and it will probably require two or three evenings to complete one of the drawings. These drawings will form a good test of the student's information, and of his skill in handling the instruments.

It is left to the instructor to give each student whatever information is thought necessary concerning the selection and size of the paper required for the drawing, and the selection and location of the various views on the sheet. This will vary with the amount of instruction the student has had in the classroom and the amount of experience he has had outside of school. It also will cover a wide range within the average drawing class.



BEVEL GEAR HOUSING
FOR ROW BOAT MOTOR

Fig. 101

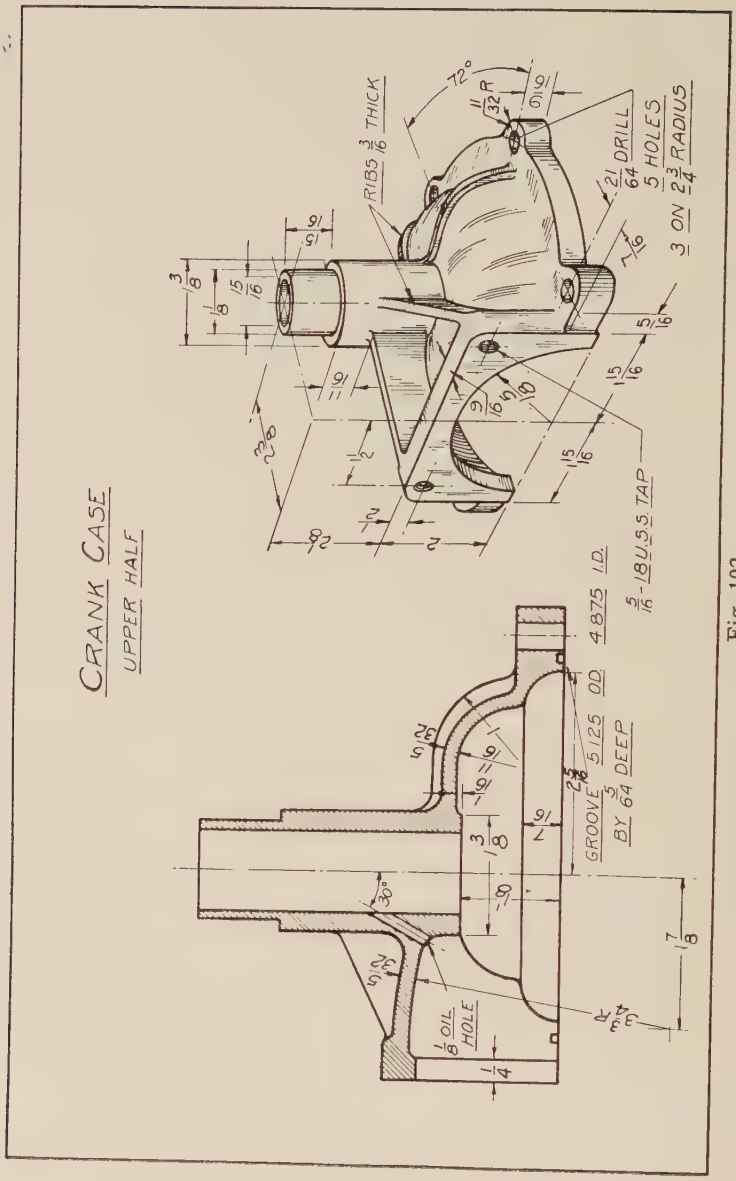

CRANK CASE
UPPER HALF
RIBS 3/16 THICK
72°
11/32 R
21/64 DRILL
5 HOLES
3 ON 2 3/4 RADIUS
5/16-18 U.S.S. TAP
4875 I.D.
5125 O.D.
GROOVE 5/64 BY 5/64 DEEP
1/8 OIL HOLE
30°

Fig. 102

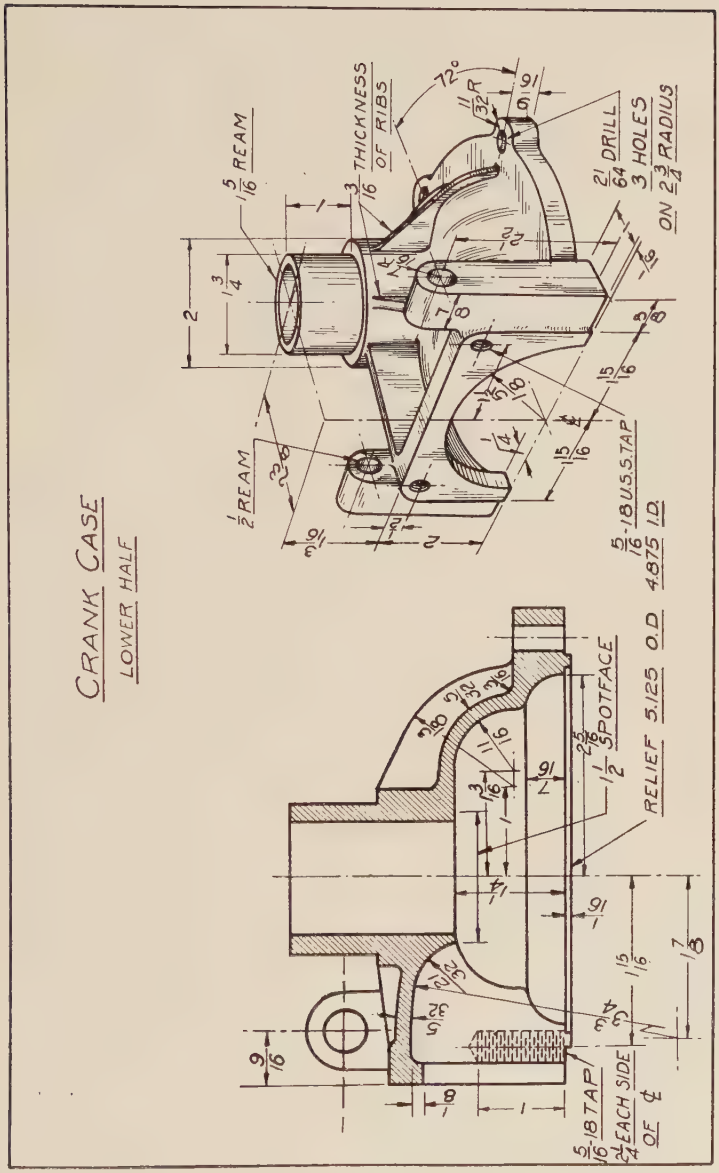

CRANK CASE
LOWER HALF
5/16 REAM
3/16 THICKNESS OF RIBS
72°
11/32 R
21/64 DRILL
3 HOLES
ON 2 3/4 RADIUS
1/2 REAM
5/16-18 U.S.S. TAP
4875 I.D.
1/2 SPOTFACE
RELIEF 5.125 O.D
5/16-18 TAP
1/4 EACH SIDE
OF ℄

Fig. 103

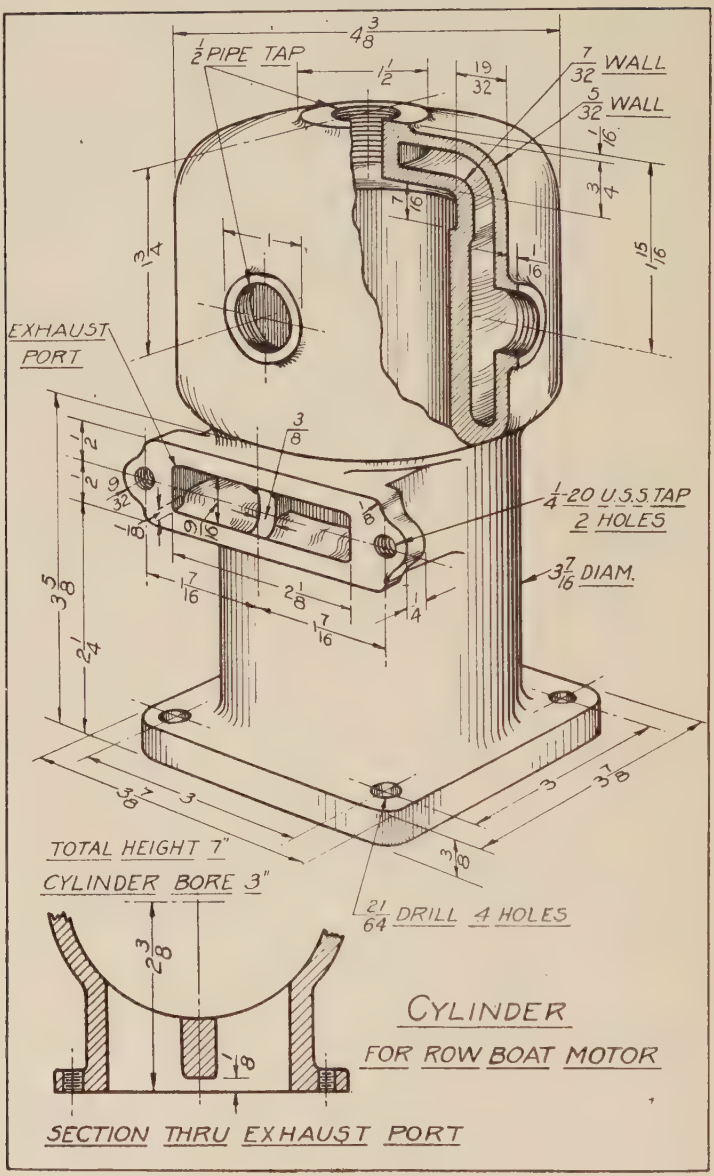

4 3/8
1/2 PIPE TAP
1/2
19/32
7/32 WALL
5/32 WALL
1/16
3/4
1 15/16
7/16
1/16
1 3/4
1
EXHAUST PORT
3/8
2
2
9/32
1/8
9/16
1/16
1/4-20 U.S.S TAP 2 HOLES
3 7/16 DIAM.
3 5/8
2 1/4
1 7/16
2 1/8
7/16
1/4
3 7/8
3
3
3 7/8
3/8
TOTAL HEIGHT 7"
CYLINDER BORE 3"
21/64 DRILL 4 HOLES
2 3/8
1/8
CYLINDER
FOR ROW BOAT MOTOR
SECTION THRU EXHAUST PORT

Fig. 104

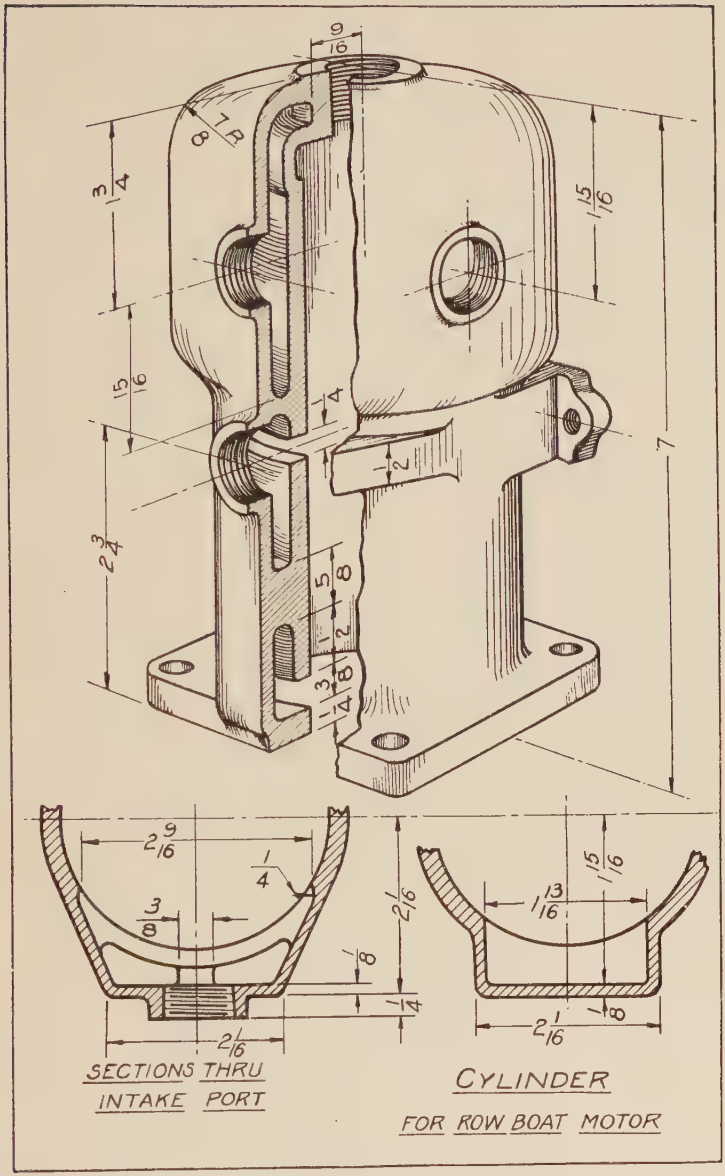

9/16
1/8 R
3/4
15/16
15/16
4
1/2
7
2 3/4
5/8
1/2
1 3/4
2 9/16
1/4
3/8
2 1/16
1/8
1/4
2 1/16
SECTIONS THRU
INTAKE PORT
15/16
1 13/16
2 1/16
1/8
CYLINDER
FOR ROW BOAT MOTOR

Fig. 104a

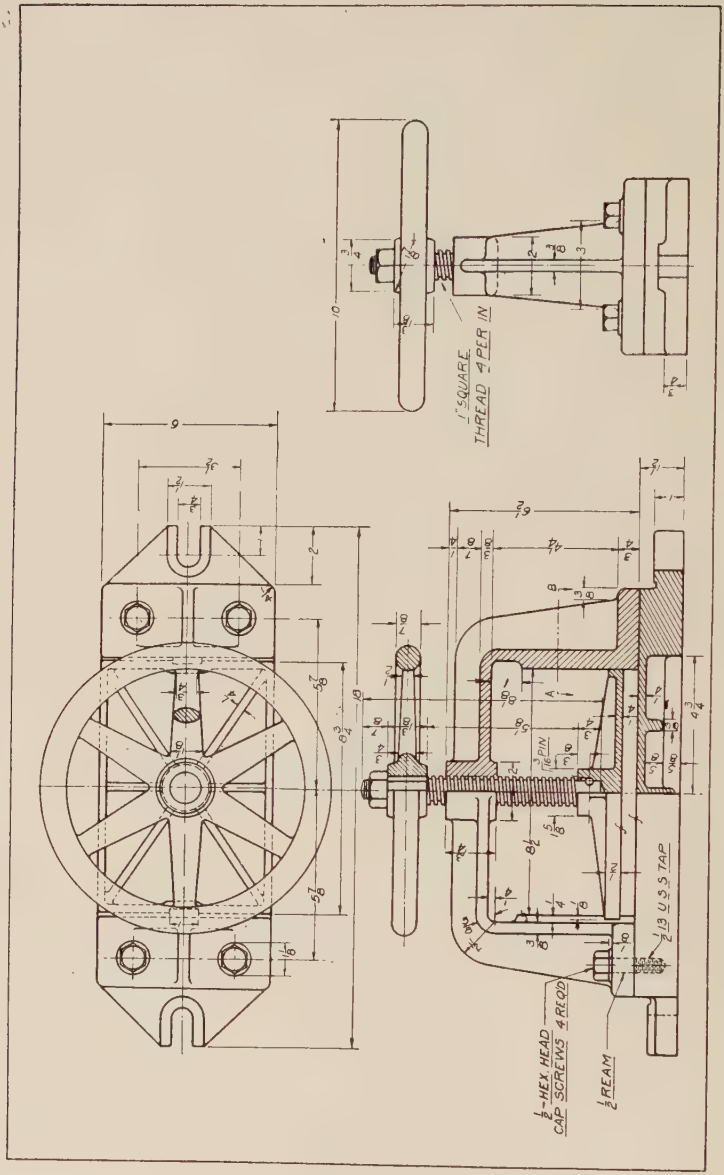

1" SQUARE
THREAD 4 PER IN
2 PIN
2 3/8 U.S.S. TAP
1/2 REAM
1/2-HEX HEAD
CAP SCREWS 4 REQD

Fig. 105

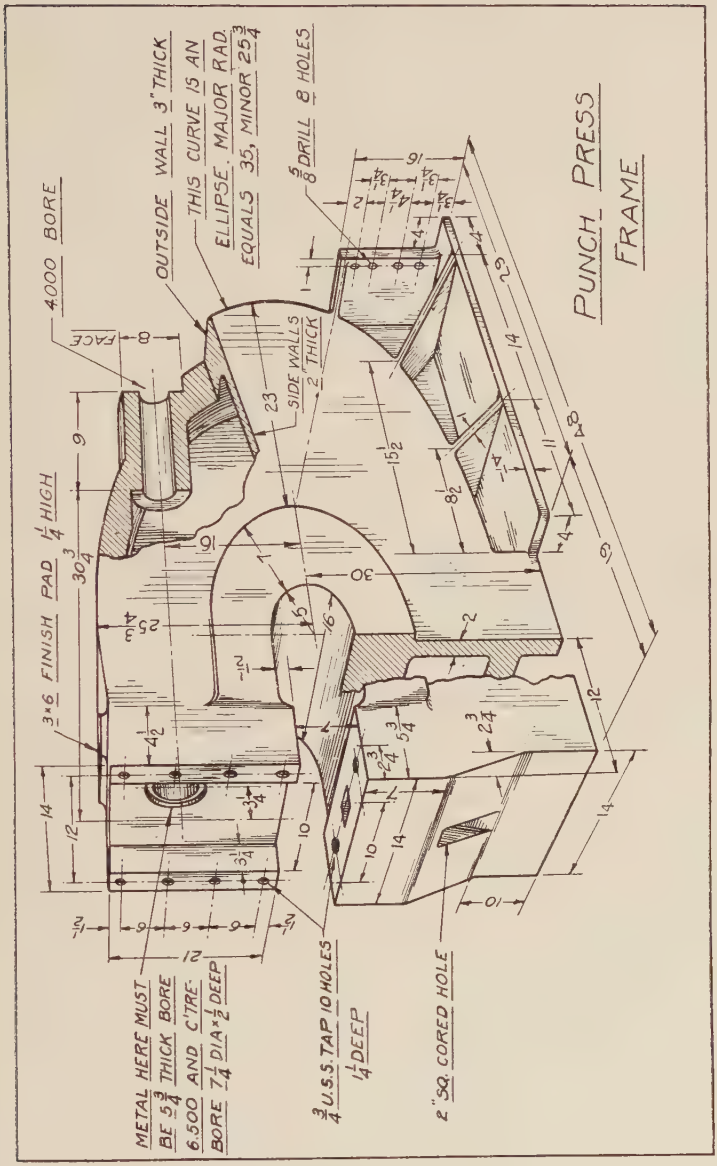

PUNCH PRESS FRAME
4000 BORE
FACE
OUTSIDE WALL 3" THICK
THIS CURVE IS AN ELLIPSE. MAJOR RAD. EQUALS 35, MINOR 25 3/4
5/8 DRILL 8 HOLES
SIDE WALLS 2" THICK
3×6 FINISH PAD 1/4 HIGH
METAL HERE MUST BE 5 3/4 THICK BORE 6.500 AND C'TRE-BORE 7 1/4 DIA × 1/2 DEEP
3/4 U.S.S. TAP 10 HOLES 1/4 DEEP
2" SQ. CORED HOLE

Fig. 106

CHAPTER VIII

SOLUTION OF TRIANGLES

The draftsman is often called upon to calculate the length of the sides of a triangle, or the angles if the sides are already known. It is not absolutely necessary to take a whole course in trigonometry in order to be able to make these calculations. A short study of the "functions" of trigonometry and the tables in which they may be found, together with the formulas for the eight possible cases of triangles, is often all that is necessary. The tables of functions can be found in any handbook, and the various cases with the formulas and an example of each case are given here, so that they may be studied and followed.

Angles. An angle is considered to be the amount of opening between two intersecting lines. Its unit of measure is the degree, written thus (°). A circle is divided into 360 parts, each of which will then be a degree. An angle of one degree (1°) can, therefore, be thought of as being a very narrow wedge, 360 of which, laid side by side with the points together, would make a complete circle.

A triangle is a plane figure having three sides and three angles made by the intersection of the sides. For convenience in calculating, the angles are denoted by the capital letters A, B, and C, while the sides opposite these angles are lettered lower-case a, b, and c, respectively.

Figure 107 is the simplest form of a triangle. One of its angles is equal to a right angle, or an angle of 90°. When two of these triangles are taken and placed in the position shown in Figure 108, they make a rectangle having side b of the triangle for its long side, and side a of the triangle for its short side. In a rectangle all the angles are right angles; this proves to us that when one of the angles of a triangle is equal to 90° then the sum of the other two angles is also 90°.

Furthermore, if A is used to represent the number of degrees in an angle, then the number of degrees in the other angle is equal to $90° - A$.

Trigonometric Functions. In order to be able to use the tables given in the handbooks, it is necessary to understand the functions of trigonometry which are six in number and represent the relation of the sides of the triangles to each other.

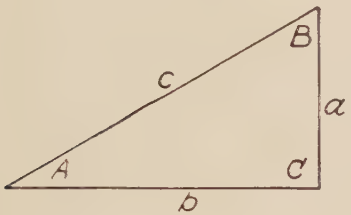


Fig. 107

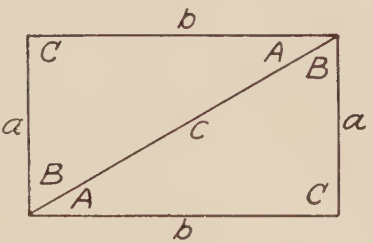


Fig. 108.

In Figure 107, angle A is to be taken under consideration. The side opposite this angle divided by the slanting side, which is called the "hypotenuse," is equal to the sine of angle A, or,

$$\frac{\text{side opposite}}{\text{hypotenuse}} = \text{sine of angle } A, \text{ or } \sin A.$$

Similarly

$$\frac{\text{side adjacent}}{\text{hypotenuse}} = \text{cosine } A, \text{ or } \cos A.$$

$$\frac{\text{side opposite}}{\text{side adjacent}} = \text{tangent } A, \text{ or } \tan A.$$

$$\frac{\text{hypotenuse}}{\text{side opposite}} = \text{cosecant } A, \text{ or cosec } A.$$

$$\frac{\text{hypotenuse}}{\text{side adjacent}} = \text{secant } A, \text{ or sec } A.$$

$$\frac{\text{side adjacent}}{\text{side opposite}} = \text{cotangent } A \text{ or cot } A.$$

For accurate work, degrees have been divided into minutes and seconds in the same way that the hours of the day

have been divided. That is, each degree is divided into sixty minutes, and each minute into sixty seconds. The following notation is used:

Degrees (°)
Minutes (′)
Seconds (″)

Tables of values for the trigonometric functions may be found in all machinists' handbooks. For machine-shop calculations it is accurate enough to obtain all angular dimensions to the nearest minute. For practice in interpolation, however, the student should carry out his answers to seconds as well.

Solution of Right Triangles. In order to be able to work out all the values for a right triangle, it is necessary to know, besides the right angle, two items in each of the four possible cases.

Case I. Two sides.
Case II. Hypotenuse and one side.
Case III. One side and one angle.
Case IV. Hypotenuse and one angle.

The formulas, and an example of each case completely worked out, follow:

Case I. Given: Sides a and b.
Figure 109.

Formulas: $\dfrac{a}{b} = \tan A$

$$\frac{b}{\cos A} = c$$

$$B = 90^\circ - A$$

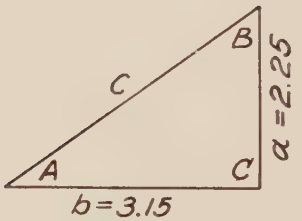


FIG. 109

Example: Given: $a = 2.25 \qquad b = 3.15$

$$\tan A = \frac{a}{b} = \frac{2.25}{3.15} = .71428 = \tan 35°32'15''$$

Therefore $A = 35°32'15''$
$B = 90° - 35°32'15'' = 54°27'45''$

$$c = \frac{b}{\cos A} = \frac{3.15}{.81374} = 3.8702.$$

Case II.
Figure 110.

Given hypotenuse c and side b.
To find: A, B, and a.

Formulas: $\dfrac{b}{c} = \cos A$

$a = b \tan A$
$B = 90° - A$

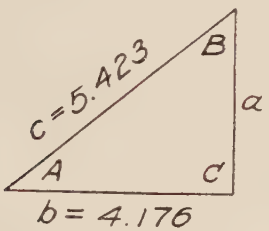


FIG 110

Example: Given: $b = 4.176 \qquad c = 5.423$

$$\cos A = \frac{4.176}{5.423} = .77005 = \cos 39°38'30''$$

$a = 4.176 \times \tan A = 4.176 \times .82850 = 3.4598$
$B = 90° = 39°38'30'' = 50°21'30''$

Case III. Given: angle A and side b.
Figure 111.

To find: a, c, and angle B.
Formulas: $B = 90° - A$
$a = b \tan A$

$$c = \frac{b}{\cos A}$$

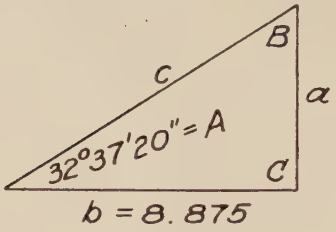


FIG. 111.

Example: Given: $A = 32° - A$ $\qquad b = 8.875$

$B = 90° - 32°37'20'' - 57°22'40''$

$a = 8.875 \times .64007 = 5.6806$

$$c = \frac{8.875}{\cos A} = \frac{8.875}{.84225} = 10.537$$

Case IV.
Figure 112.

Given: angle A and hypotenuse c.
To find: sides a and b and angle B.
Formulas: $B = 90° - A$
$b = c \cos A$
$a = c \sin A$

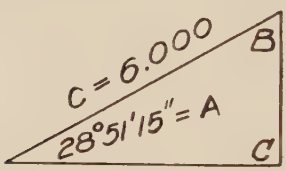


FIG. 112.

Example: Given: $c = 6.000$ $\qquad A = 28°51'15''$

$B = 90° - 28°51'15'' = 61°8'45''$

$b = 6.000 \cos A = 6.000 \times .8756 = 5.2536$

$c = 6.000 \sin A = 6.000 \times .48258 = 2.89548$

Oblique Triangles. Oblique triangles have no right angle, and may be divided into two classes: acute and obtuse-angle triangles. *Acute*-angle triangles have no angle greater than 90°. *Obtuse*-angle triangles have one angle greater than 90°. They are shown in Figures 113 and 114 respectively.

In order to solve the triangles illustrated in Figure 113, we have the following laws of trigonometry:

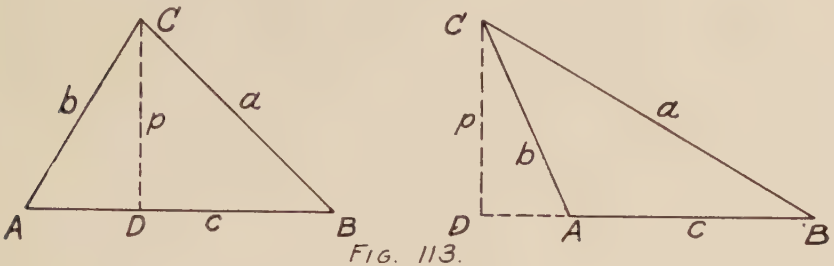


FIG. 113.

Law of Sines

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

Law of Cosines

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$

Law of Tangents

$$\tan \frac{A - B}{2} = \frac{a - b}{a + b} \cot \frac{C}{2}$$

In solving oblique triangles, it is necessary to have the following information with which to work:

Case I. One side and two angles.
Case II. Two sides and the angle opposite one of them.
Case III. Two sides and the included angle.
Case IV. Three sides.

Case I. One side and two angles.
Figure 114.

Given: a, A, and B
To find: C, b, and c
Formulas: $C = 180° - (A + B)$

$$b = a \frac{\sin B}{\sin C}$$

$$c = a \frac{\sin C}{\sin A}$$

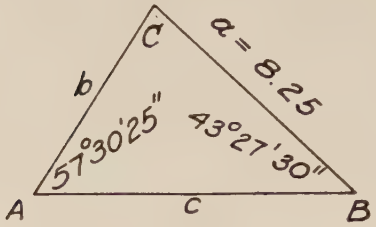


FIG. 114.

Example: $a = 8.25$
$A = 57°30'25''$
$B = 43°27'30''$
$C = 180° - (A + B) = 180° - 100°57'55'' = 79°2'5''$

$$b = 8.25 \times \frac{\sin B}{\sin A} = 8.25 \times \frac{.68782}{.84346} = 6.728$$

$$c = 8.25 \times \frac{\sin C}{\sin A} = 8.25 \times \frac{.98168}{.84346} = 9.6019$$

Case II. Two sides and the angle opposite one of them.
Figure 115. Given: a, b, and A

To find: B, C, and c.

Formulas: $\sin B = b \dfrac{\sin A}{a}$

$$C = 180° - (A + B)$$

$$c = a \frac{\sin C}{\sin A}$$

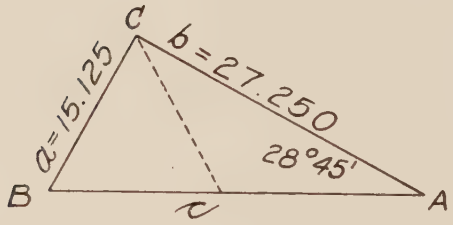


FIG. 115.

Under varying conditions there may be none, one, or two solutions to this case.

Figure 116. If $\frac{a}{b}$ is greater than sine A there are two solutions.

Figure 117. If $\frac{a}{b}$ is equal to sine A there is one solution.

Figure 118. If $\frac{a}{b}$ is less than sine A there is no solution.

Lines a and c would not meet.

FIG. 116.

FIG. 117.

FIG. 118.

Given: a equals 15.125 b equals 27.250 A equals 28°45′
To find: B, C, and c.
a equals .55504 sin 28°45′ equals .48099

There are two solutions. $\frac{a}{b}$ is greater

$$\sin B = 27.250 \times \frac{.48099}{15.125} = 8.4013 = \sin 60°3'49''$$

The sine of 60°3′49″ also equals the sine of 180° — 60°3′49″ = 119°56′11″

$$C = 180° - \frac{(A + B)}{91°11'11''} = 180° - (28°45' + 60°3'49'') =$$

$$\text{also } C = 180° - \frac{(A + B)}{31°18'49''} = 180° - (28°45' + 119°56'11'') =$$

$$\begin{aligned} \sin 91°11'11'' &= \sin 180° - 91°11'11'' \\ &= \sin 88°48'49'' = .99979 \\ &\quad \sin 31°18'49'' = .51972 \end{aligned}$$

Therefore: $C = 15.125 \times \dfrac{.99979}{.48099} = 31.4597$

also $C = 15.125 \times \dfrac{.51972}{.48099} = 16.342$

When a triangle of this type occurs in machine drawing, there always are conditions to determine which of the two values for C and c are to be used.

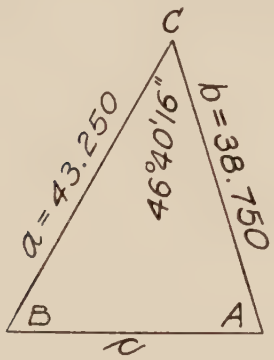


FIG. 119.

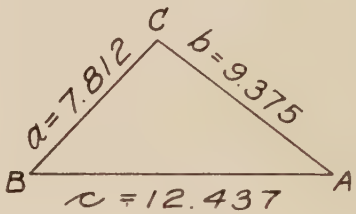


FIG. 120.

Case III. Two sides and included angle.
Figure 119.

Given: a, b, and C
To find: A, B, and c

Formulas: $\tan \dfrac{A - B}{2} = \dfrac{a - b}{a + b} \cdot \dfrac{\cot C}{2}$

$A + B = 180° - C$

Example: Given: $a = 43.250$
$b = 38.750$
$C = 46°40'16''$

$$\tan \frac{A + B}{2} = \frac{4.500}{82.00} \cdot \cot \frac{46°40'16''}{2} = \frac{4.500}{82.00} \cot 23°20'8'' =$$

$$\frac{4.500}{82.000} : 2.318 = .12718 = \tan \frac{A - B}{2} = \tan 7°15'4''$$

$A - B - 14°30'8''$

$179°59'60''$ $\qquad A + B = 133°19'44''$ $\qquad A + B = 133°19'44''$

$46°40'16''$ $\qquad A - B = \ 14°30'\ 8''$ $\qquad A - B = \ 14°30'\ 8''$

$134°19'44''$ $\qquad 2A = 147°49'52''$ $\qquad 2B = 118°49'36''$

$A = \ 73°54'56''$ $\qquad B = \ 59°24'48''$

$C = \ 46°40'16''$

$a = 43.250$

$b = 38.750$

$c =$

$$\frac{a}{\sin A} = \frac{c}{\sin C} = \frac{43.250}{\sin 73°54'56''} = \frac{c}{\sin 46°40'16''} =$$

$$c = \frac{43.250 \cdot \sin 46°40'16''}{\sin 73°54'56''} = \frac{43.250 \cdot .72742}{.96085} = 32.742$$

Case IV. Given three sides a, b, and c.
Figure 120.

To find all angles A, B, and C.

Formulas: $\cos A = \dfrac{b^2 + c^2 - a^2}{2\,bc}$

$$\cos B = \frac{a^2 + c^2 - b^2}{2\,ab}$$

$$\cos C = \frac{a^2 + b^2 - c^2}{2\,ab}$$

also $\sin B = \dfrac{b \sin A}{a}$

$$C = 180° - (A + B)$$

Example: Given: $a = \ 7.812$

$b = \ 9.375$

$c = 12.437$

To find: A, B, and C.

$$\cos A = \frac{b^2 + c^2 - a^2}{2\,bc} = \frac{87.891 + 154.679 - 61.027}{233.194}$$

$$= \frac{181.533}{233.194} = .77846 = \cos 38°52'24''$$

$$A = 38°52'24''$$

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

$$\sin B = \frac{b \sin A}{a} = \frac{9.375 \times .62763}{7.8125} = .740403$$

$$B = \sin 48°52'1''$$

$$180° - (A + B) = C = 180° - (38°52'24'' + 48°52'1'')$$

$$= 92°15'35''$$

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Brent Malin